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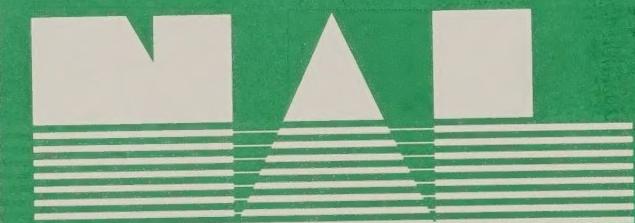
FHTET 96-24  
January 1997



# Gypsy Moth Expert System (GypsES) Review

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# Management summary

This review of the GypsES (Gypsy Moth Expert System) software development project was conducted by Forest Health Technology Enterprise Team (Enterprise Team) staff in conjunction with the GypsES development team to analyze the history and current status of the project. More importantly, it was conducted to provide a focal point for Forest Health Protection (FHP) managers to address questions related to future FHP sponsorship of the project, options for its continued development and maintenance, and questions concerning the product's costs and benefits. This review attempts to sort through and clarify the issues raised in recent discussions about the above items within FHP. This report does not attempt to answer questions which were deemed to be the responsibility of FHP management.

The GypsES project began in 1988 as a research endeavor by the Northeastern Forest Experiment Station. FHP became financially involved in 1991; since then its role has expanded. Today, FHP staff in the Southern Region and the Northeast Area play lead roles in the ongoing development and maintenance of the GypsES project. In more recent years, sponsorship and funding has grown more tenuous. Due partly to the manner in which this project began and partly to the uncertain nature of the funding, year-to-year project activities are dictated more by available funding than by a master plan. As with any project, limited resources result in hard choices. As a result, some important components of the GypsES product are lagging.

Lack of complete documentation has probably discouraged the development team from labeling recent versions of GypsES as version 1.0. GypsES, as it exists today, is a technically complex yet user-friendly decision support system designed to support many tasks related to gypsy moth suppression and eradication projects. GypsES includes necessary Geographic Information Systems (GIS) functions, database management functions, and reporting functions to support these tasks. Also, a half dozen or so preexisting analytical tools such as defoliation predication models are integrated within GypsES.

The primary target end-user for GypsES was and continues to be state and county entities charged with managing the bulk of gypsy moth suppression and eradication projects in the United States. As such, a primary user requirement driving the design of GypsES was that it be affordable to implement and use. Thus, rather than being built using existing and relatively expensive commercial software, GypsES is largely custom-coded, consisting of about 200,000 lines of code.

As a highly customized system operating on a PC-based UNIX operating system, GypsES requires specific microcomputer and related hardware components in order to operate. Most microcomputer peripherals do not come with software to operate under PC-based UNIX systems. Because of this, low-level driver software must often be developed in order to integrate the constantly changing hardware components. The nature of this issue and the complexity of a PC-based UNIX system in general dictate that the GypsES development team perform hardware setup, installation of software, and data preparation in order to deliver a turnkey system to the user site. Chances are slim that a user site has the exact hardware components needed prior to implementing GypsES. Thus, hardware purchases are usually necessary to allow use of GypsES.

Partly because of the complexity of GypsES and partly to ensure successful use of GypsES, the development team provides an exceptional level of support/service to end-user sites. This level of service may currently consume as much as half of the current resources spent on this project. As the user base grows, these support expenses will grow commensurately. End users are generally not paying for this support. Considering the volume of software code, the operating system issues, the hardware requirements, and the breakneck pace of technology change in general, maintenance costs for GypsES will definitely not dissipate and may likely increase with increases in the user base.

Since the first prototype of GypsES was delivered to Prince William County, Virginia, in 1992, the user base has grown to over 18, with most of the growth in 1995 and 1996. In these last two years, GypsES has matured into an operational system that is highly functional and well liked by end-users. This satisfaction is evident in recent growth, as Animal and Plant Inspection Service (APHIS) and Department of Defense (DOD) staffs are now in the process of implementing GypsES. This satisfaction is also evident in the funding support that is emerging from these two interested organizations.

Use of GypsES provides substantial benefits to FHP in its role of protecting and restoring forest health. Experience to date indicates a 20 percent savings in traditional gypsy moth suppression and eradication program costs with the use of GypsES. In a suppression/eradication program that typically spends \$1 million per year, this could mean \$200,000 in savings if most state and county entities were using GypsES. The non-quantifiable benefits are perhaps more substantial than the labor and material items noted. These benefits include improved public relations, improved program delivery, and improved mechanisms for putting research findings to practical use.

Through fiscal year (FY) 1996, a minimum of \$1.4 million has been spent on the GypsES project. Approximately half of this total came from FHP funds. In Fiscal Year (FY) 1997, the GypsES budget will total \$215,000. These figures represent minimums, because they do not include federal salaries for some development team members. These additional salary costs are substantial. Of the FY 1997 figure, \$130,000 comes from FHP. The FY 1997 level of funding will probably need to be sustained over the next several years to sustain the project, especially in light of the growing user base. The development team consists of eight Forest Service employees who spend from five to 100 percent of their time on GypsES.

Foremost among the recommendations to the development team are:

- Reach closure on version 1.0 of GypsES as soon as possible so that it represents a complete, stable package.
- Isolate new development/enhancements and maintenance/support activities into two separate tasks so that leadership can more clearly assess costs, benefits, and the appropriate roles for FHP, the end-users, and other cooperators.
- Annually, if not semiannually, formally review technology options for delivering the functionality within GypsES and document the results of these reviews. GypsES, as a highly customized system, is likely to continue to require above-average maintenance costs. With technology change there are likely to be opportunities to reduce these costs.

FHP executive leadership has an important role in the GypsES project that includes:

- Ensuring leadership is engaged in the project beyond initial project sponsorship and funding.
- Being involved in defining project goals, objectives, and deliverables.
- Recognizing the need for consistent senior management level involvement.

FHP executive leadership needs to clearly address several questions that affect the future of this project. Some key questions include:

- Are the benefits of GypsES to FHP worth the costs to FHP now and in the future?
- Should new development continue for this system, should the system be maintained as is until it can be re-engineered using other commercial software with hopes of reducing maintenance/support costs, or should the effort be abandoned?
- What level of support in terms of staff time, funding, and management involvement will FHP commit to? For which activities?
- Is this level of commitment realistic to sustain the project?

Readers should refer to the Findings and recommendations section of this document (pages 51-57) for more details on the above issues as well as for a more complete list of recommendations, observations, and questions for management.



# Background

The Gypsy Moth Expert System (GypsES) project has been active since 1988. It represents a large investment by the USDA Forest Service Northeastern Forest Experiment Station (NE) and the USDA Forest Service Forest Health Protection (FHP) staffs. Recent discussions of issues related to GypsES and other FHP-sponsored computer systems development efforts indicated the need for a detailed review of long-term maintenance, staff responsibilities, cooperator responsibilities, level of investment, and other related issues. This report presents the results of that review.

## What is GypsES?

GypsES is a personal computer-based, decision support system with a rich array of functions. It is used to support gypsy moth suppression and eradication projects. The system includes a user-friendly interface customized to fit the sequence of planning, implementation, and monitoring tasks (See Figure 1). It provides access to system-provided functions and various analytical tools integrated into the system. GypsES gives its users access to Geographic Information Systems (GIS) functions to manipulate and produce maps and other spatial products; data management functions to collect, analyze, summarize, and transform project data; and a variety of analytical tools (e.g., hazard rating, phenology, spray dispersion models) to support decision making. Its

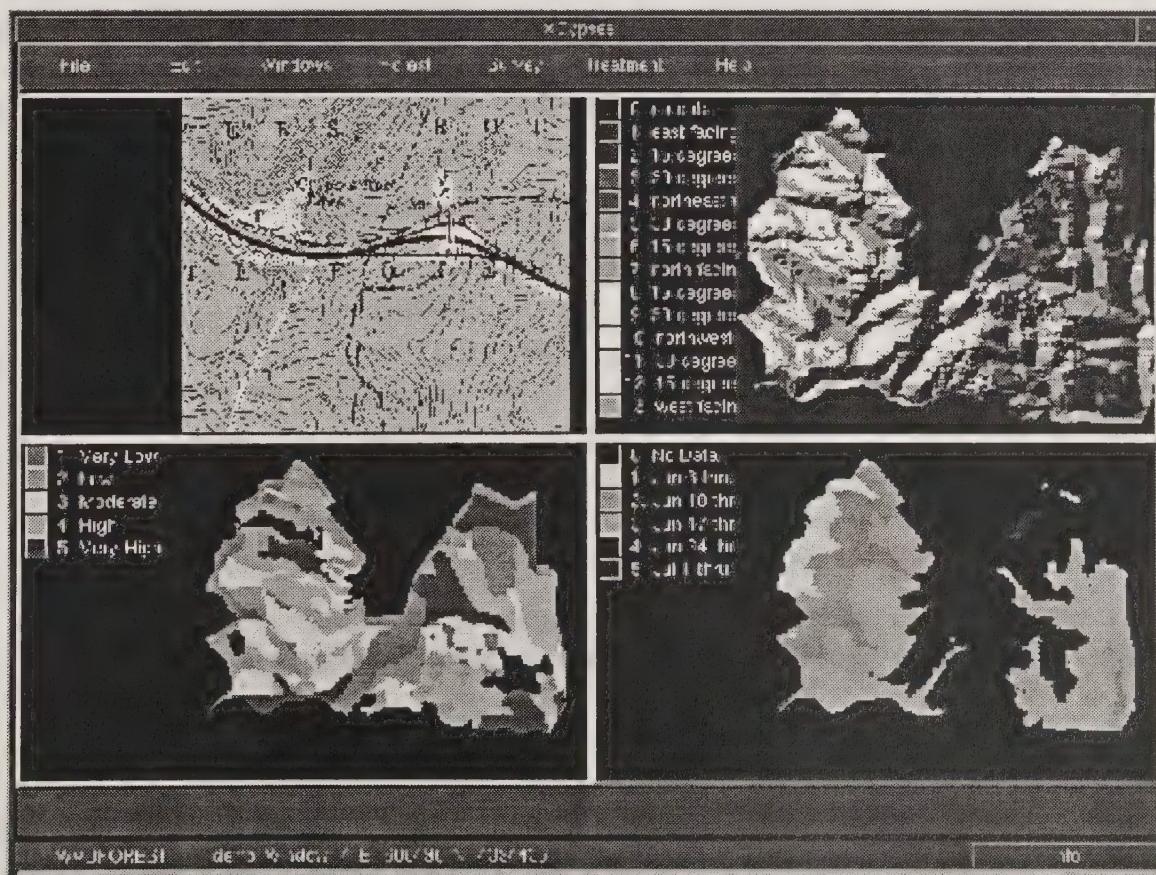


Figure 1. GypsES in tiled mode. WVU Forest location. Upper left: Quad Map; Upper right: Aspect; Lower left: Hazard Rating; Lower Right: Grouped Phenology

personal computer-based operating system allows GypsES to be used both in field offices on desktop systems and in the field on notebook computers. GypsES is typically used by gypsy moth managers from the spring to late fall of each year. It supports all aspects of gypsy moth suppression and eradication projects. The section of this report entitled **GypsES functions** (see page 5) contains more detailed information about GypsES functionality.

In the eyes of the typical end-user, GypsES represents more than just software as described above. GypsES is a turnkey, Forest Service-supported system where pre-configured hardware, software, and data are delivered to the user with follow-up support provided by FHP staff. This broader definition of GypsES is critical to understanding this report, since many important facets of the GypsES project reflect more than development of computer software code in general. A full understanding of GypsES requires an understanding of issues relating to the operating system that GypsES runs on, the specific hardware requirements of GypsES, the data acquisition and configuration tasks related to its use, the level of support delivered to end-users, and the use of GypsES software as a vehicle for day-to-day interactions between FHP and end-users.

## Objectives of this review

As GypsES evolved from an idea in 1988 to an operational product in 1995, discussions among developers and managers began to focus on the level of effort required to support the operational life of the software, responsibility for sustaining this effort, how development/resource costs could be controlled and shared, and whether the cost to Forest Health Protection of sustaining this effort was justified. Given these discussions, the Forest Health Protection Technology Enterprise Team (Enterprise Team) of the FHP staff agreed to conduct an extensive review of GypsES in FY 1996. The objective of this review was to examine these issues to enable managers to:

- Understand the issues and provide clear direction to the GypsES team.
- Identify and pursue opportunities to share responsibility for project components (i.e., analysis, development, maintenance, support) both internally across Forest Health Protection staffs and externally with other partners.
- Specifically identify any potential role of the Enterprise Team.
- Understand the complexity of software development and the full costs and benefits of GypsES so that future initiatives can be fairly evaluated and either supported or ended.
- Use this information to reflect on all software development efforts sponsored by FHP to leverage FHP's ability to efficiently and effectively choose and guide future efforts.

## **How this review was conducted**

The review of the GypsES project was a cooperative effort by members of the GypsES development team and members of the Enterprise Team. The GypsES development team members who took part were:

Dan Twardus, Forest Health Protection Specialist  
Forest Health Protection Northeast Area  
Morgantown Field Office, Morgantown, WV

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Northeastern Forest Experiment Station  
Morgantown, WV

John Ghent, Entomologist  
Forest Health Protection, Southern Region  
Asheville Field Office, Asheville, NC

Susan Thomas, Computer Specialist  
Northeastern Forest Experiment Station  
Morgantown, WV

David Breakey, Computer Specialist  
Forest Health Protection, Northeast Area  
Morgantown Field Office, Morgantown, WV

Douglas Mason, Computer Specialist  
Northeastern Forest Experiment Station  
Morgantown, WV

Anne Cummings, Data Development and Acquisition Specialist  
Northeastern Forest Experiment Station  
Morgantown, WV

The Enterprise Team review team consisted of:

Stephen Williams, Computer Specialist and Team Leader  
Fort Collins, CO

Matt Thompson, Information Systems Analyst  
Management Assistance Corporation of America, Fort Collins, CO

Dave Roschke, Computer Specialist  
Fort Collins, CO

The structured review process followed a specific outline of issue categories with a fairly large set of mostly open-ended questions in each category (see Appendix A, page 65). The issue

categories generally match the sections that form this report. These issue categories and the associated questions were drafted by the Enterprise Team based on personal knowledge and a review of the problems, successes, and policies encountered on previous and current software development projects with which the Enterprise Team has been and is involved. The GypsES development team reviewed and commented on the draft document; after several iterations, the eight-page review instrument was finalized.

Although some information and documents to support the review were gathered and analyzed before the formal meeting, most of the information and analysis was derived from a two-day meeting held August 21 and 22, 1996, in Morgantown, WV. All team members listed above, except for John Ghent, participated in this meeting. During the two-day meeting the questions in the review instrument were thoroughly discussed. Answers were documented.

Following the August meeting, the GypsES development team gathered more detailed information to supplement the discussions and sent it to the Enterprise Team. The text of this report was written by the Enterprise Team with input from the GypsES team and reviewed for accuracy, clarification, and comment by the GypsES team.

## How to Use this Report

This report, organized in sections which roughly correspond to the logical divisions of the GypsES status evaluation guide (attached as Appendix A), covers the following topic areas:

- Management summary.
- Background.
- GypsES functions.
- Customer analysis.
- Benefits to Forest Health Protection.
- Design issues.
- Standards adherence.
- Software documentation.
- Testing and error handling.
- Development history in terms of cost.
- Implementation, system administration, and maintenance issues.
- Future development plans.
- Findings and recommendations.
- References.
- Acronym list and glossary.

**Appendix B, User information**, contains details of the Customer analysis of GypsES users that is summarized in Table 2 on page 18. Copies of the following supporting documents are also included as Appendices C-F:

Gottschalk, K.W., et al. 1995. GypsES: A decision support system for gypsy moth management. Paper presented at Decision Support Systems for Forest Pest Management Workshop at Entomological Society of Canada/Entomological Society of British Columbia Annual Meeting, 14-19 October 1995, Victoria, B.C. (Appendix C.)

Twardus, D.B., et al. 1996. An overview of GypsES: The gypsy moth decision support system. Presented at the 1996 ASAE Annual International Meeting, 14-18 July 1996. ASAE Paper No. 961035. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA. (Appendix D.)

Ghent, J.H., et al. 1996. A demonstration of GypsES: The gypsy moth decision support system. Presented at the 1996 ASAE Annual International Meeting, 14-18 July 1996. ASAE Paper No. 961036. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA. (Appendix E.)

Teske, M.E., et al. 1996. An FSCBG sensitivity study for decision support systems. Presented at the 1996 ASAE Annual International Meeting, 14-18 July 1996. ASAE Paper No. 961037. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA. (Appendix F.)

This report is designed so that the reader may consult the Management summary (pages 1-3) for a general overview of the results of the GypsES Project review. Where further information is desired on a given topic area, the reader may go directly to that area. If more detailed information is needed, the reader may consult the appropriate supporting documents in the appendices.



# GypsES functions

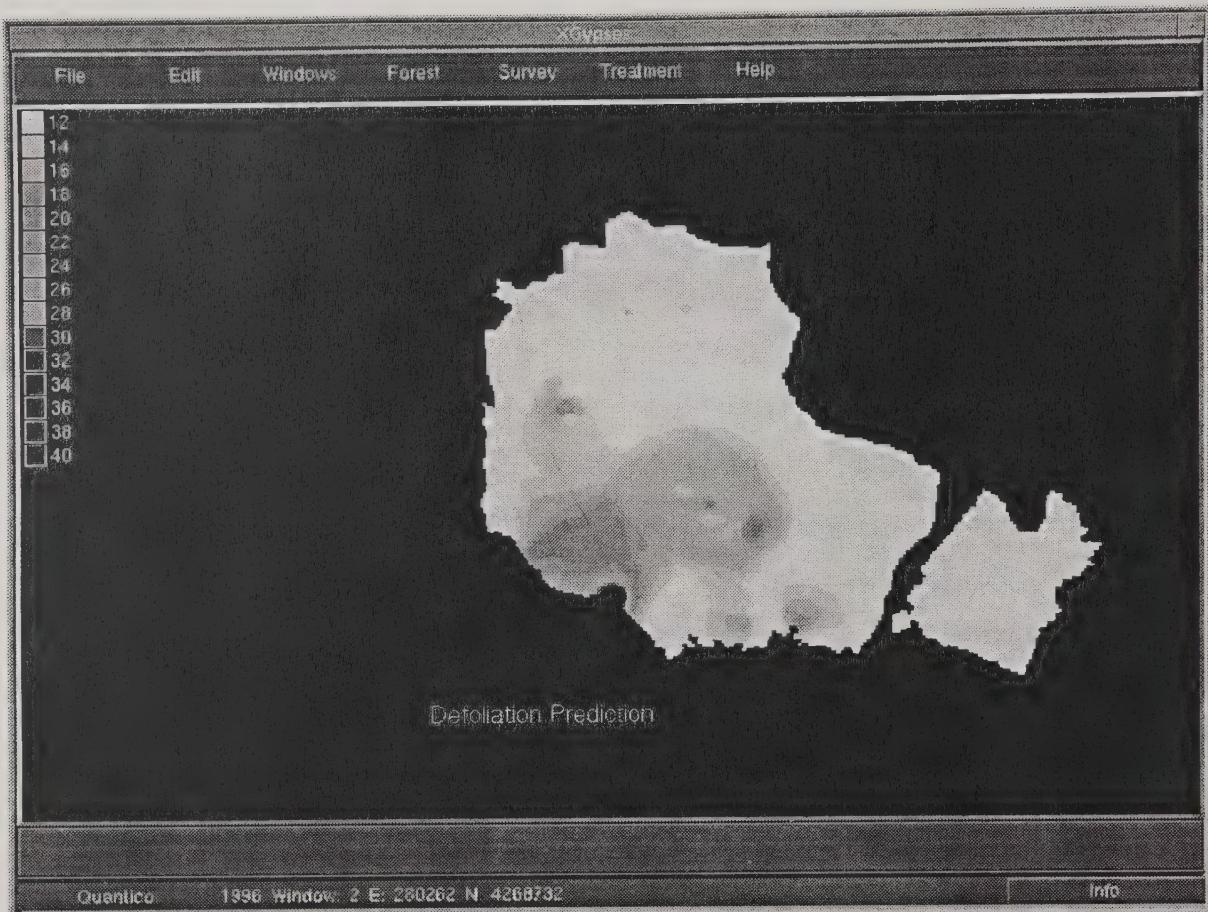
Resource management efforts to suppress or eradicate the gypsy moth include a complex array of tasks. These efforts involve many people and coordination across multiple levels of government. (Gottschalk et al 1996; see Appendix D). Some of these tasks are:

- Design trap placement plans for pheromone traps.
- Assign responsibility for trap placement.
- Monitor progress on trap placement and trap data collection.
- Gather and analyze trap data.
- Design egg-mass sampling programs and implement them.
- Gather and analyze egg-mass count data.
- Use various analytical tools such as hazard-rating models to assess potential problems.
- Plan and design a time-sensitive treatment program which suppresses or eradicates gypsy moths on high-risk areas.
- Manage pesticide spray operations.
- Evaluate the effectiveness and accuracy of spray operations.
- Evaluate gypsy moth trends over time.
- Evaluate performance of personnel and contractors.

The software functions incorporated into GypsES were designed to support specific tasks undertaken as part of annual activities of gypsy moth suppression and eradication projects. More detailed descriptions of these functions and explanations of their importance are contained in Appendices C through F. A summary of the main capabilities of GypsES follows.

## GypsES GIS capabilities

The set of GypsES GIS functions is provided through a subset of Geographic Resource Analysis Support System (GRASS) functions and custom-coded functions. GypsES GIS functions work with a site-specific library of basic GRASS format spatial layers and other supporting Tagged Image File Format (TIFF) images, such as quad sheets and satellite imagery. The GIS functions support map analysis, the creation of new map sets, and on-screen digitizing with topographic map backdrops. The user can, among other uses, use GypsES to design the layout of sampling grids for pheromone, egg-mass, or larval sampling; define spray blocks; and view spatial output information from models (See Figure 2). GypsES GIS functions are leveraged by their linkage with GypsES database and data export functions. For example, the pheromone, egg-mass, or larval sampling layers are associated with data tables which are used to store and track these sampling activities. Likewise, the spray-block layers can be easily converted to Global Positioning System (GPS)-readable files and uploaded for use by the pilot during gypsy moth spray operations.



**Figure 2.** Defoliation prediction based on egg-mass survey (Gansner Model) for Quantico Marine Base in Virginia.

The GIS functions of GypsES include only those needed to support specific activities for gypsy moth management. Therefore, they do not necessarily include all the functionality that someone involved with general spatial analysis tasks might desire.

## Access to gypsy moth-related models

Most models integrated into GypsES existed before the creation of GypsES. However, as is the case with many natural resource analysis tools, some of these models were not widely used because of the difficulty of preparing input data and the lack of an intuitive interface. GypsES both provides a common interface for these integrated tools and facilitates their use. For many of these tools, the integration included development of a new user-friendly interface specifically to support use of that tool.

### Defoliation prediction models

Two gypsy moth defoliation prediction models are available through GypsES. Input to drive these models can be either an individual egg-mass sample plot or an egg-mass surface generated by GypsES using the egg-mass sample plots. So used, the input predicts gypsy moth-caused defoliation (See Figure 2). The output of these defoliation models can also be used as input to the hazard-rating model to estimate risk.

## **Hazard-rating Model**

The Hazard-rating Model within GypsES, developed in conjunction with the GypsES project, is well integrated into GypsES. This model works in conjunction with several GypsES components. One of these components determines susceptibility of trees on a land unit to defoliation by gypsy moth. Another determines the vulnerability of those trees based on susceptibility and other land-unit attributes (the hazard-rating component). A third determines risk based on hazard rating in combination with gypsy moth population trends. The design of this system of components allows the user to deal with situations where the ideal datasets to drive the components are not available.

The integration of the Hazard-rating Model into the GypsES framework demonstrates the value of integrating multiple tools, since outputs from this model can be used easily as input for the module of GypsES which facilitates gypsy moth-sampling activities.

## **Stand-damage Model**

The Stand-damage Model is a stand-alone model developed as part of the Gypsy Moth Life Systems Model (Colbert and Sheehan, 1995). It simulates forest growth, mortality, and regeneration, and includes the ability to apply defoliation percentages to trees present in the simulated stand. The Stand-damage model can be run interactively from within GypsES. The program spawns the model and then runs it independently from GypsES. The model can also be run by using predefined scenarios integrated into GypsES, thus bypassing the model's own interface. The latter way of running the model allows the outputs from the Stand-damage Model to be fed back into GypsES automatically for graphic display. The outputs from this model include economic information, such as basal area or volume loss in terms of board-foot values.

## **Gypsy Moth Phenology Model (GMPHEN)**

The GMPHEN Model was developed as part of the Gypsy Moth Life System Model (Sheehan 1992) and was extracted by the GypsES project team as a stand-alone version. GMPHEN uses daily maximum and minimum temperatures to calculate heat accumulation measured in degree-days. The results from the model are displayed as phenology layers that can be used for planning many operations, including organizing spray blocks into units of similar phenology, timing spray applications for maximal efficacy, planning pheromone trap placement and pickup, and timing pheromone application for mating disruption.

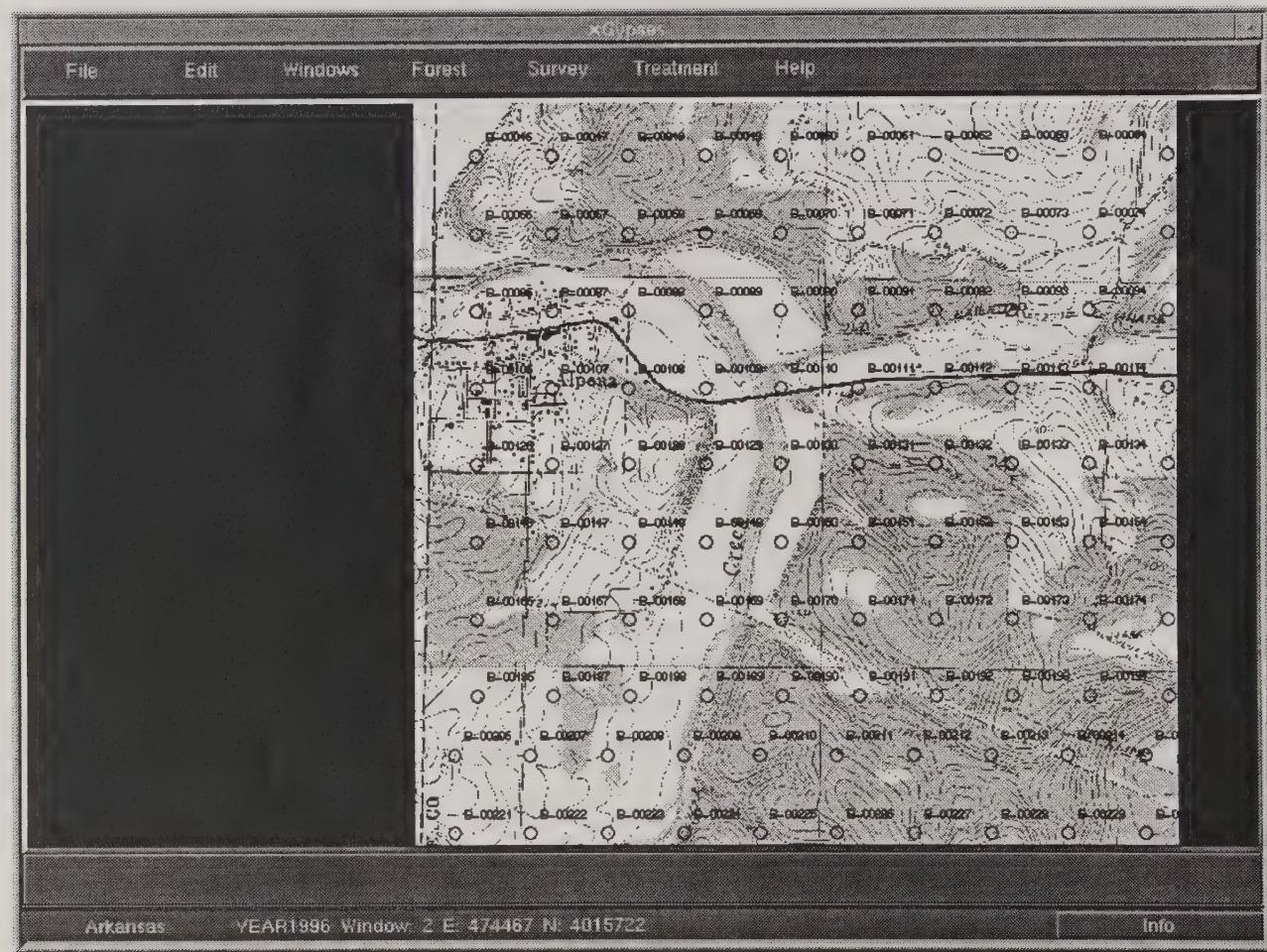
## **FSCBG Spray Deposit and Drift Model**

The Forest Service Cramer-Barry-Grim (FSCBG) model is a tool recently integrated into GypsES. It predicts pesticide/biochemical spray deposit within a treatment area and potential drift to exclusion zones nearby (Teske et al 1993; see Appendix F, pages 121-132). The GypsES developers created a user-friendly interface in GypsES to provide an easier way of using FSCBG.

## Pest survey and monitoring support functions

Gypses includes software functions to support design of gypsy moth sampling plans, management of ongoing pest surveys, and analysis of survey data to support other suppression/eradication activities.

The sampling and monitoring support component of GypsES provides a user with a spatially oriented means to design the layout of sampling grids for pheromone, egg-mass, or larval sampling (See Figure 3). The user can track the placement of pheromone traps or sampling plots, record sampling data through data entry screens, analyze survey data, and use the results to generate density estimate layers. The results of sampling efforts provide data that is used along with other information to set up and prioritize management unit strategies, including eradication, suppression, or silvicultural alternatives.



**Figure 3. Arkansas Eradication Project Area with 7.5 minute quad backdrop and trap grid sites.**

The survey and monitoring functions may be accessed by means of either the suppression mode or the eradication mode. Suppression mode gives access to the subset of functions that supports the need to control established gypsy moth populations. Eradication mode gives access to a slightly different subset of functions needed to support management tasks where the goal is to eliminate the insect in areas outside of the generally infested zone.

## GypsES treatment function

Many automated functions are available to facilitate management of a gypsy moth treatment program—a program where decision makers must define which land units require treatment with a gypsy moth control substance, the timing of when to spray these units with the substance, and which pilot/plane will be used. These functions include generating and using a risk layer for the project area to highlight candidate treatment sites; defining a spray-block layer using the on-screen digitizing facility; scheduling the timing of spray operations through use of the phenology layer; uploading spray-block boundaries to spray plane global positioning systems (GPS); and evaluating spray drift scenarios using FSCBG. Post-treatment functions are also included to evaluate the effectiveness of the treatment program.

## GypsES GPS Support

Although GypsES GPS support was referenced in the above section and is considered a treatment-related function, it has some unique features which are highlighted here.

The GPS support function allows the user to upload and download spray block and spray line information through global positioning system files (See Figure 4). These files are loaded into the GPS systems on the airplane to guide the pilot during spraying operations. During missions,

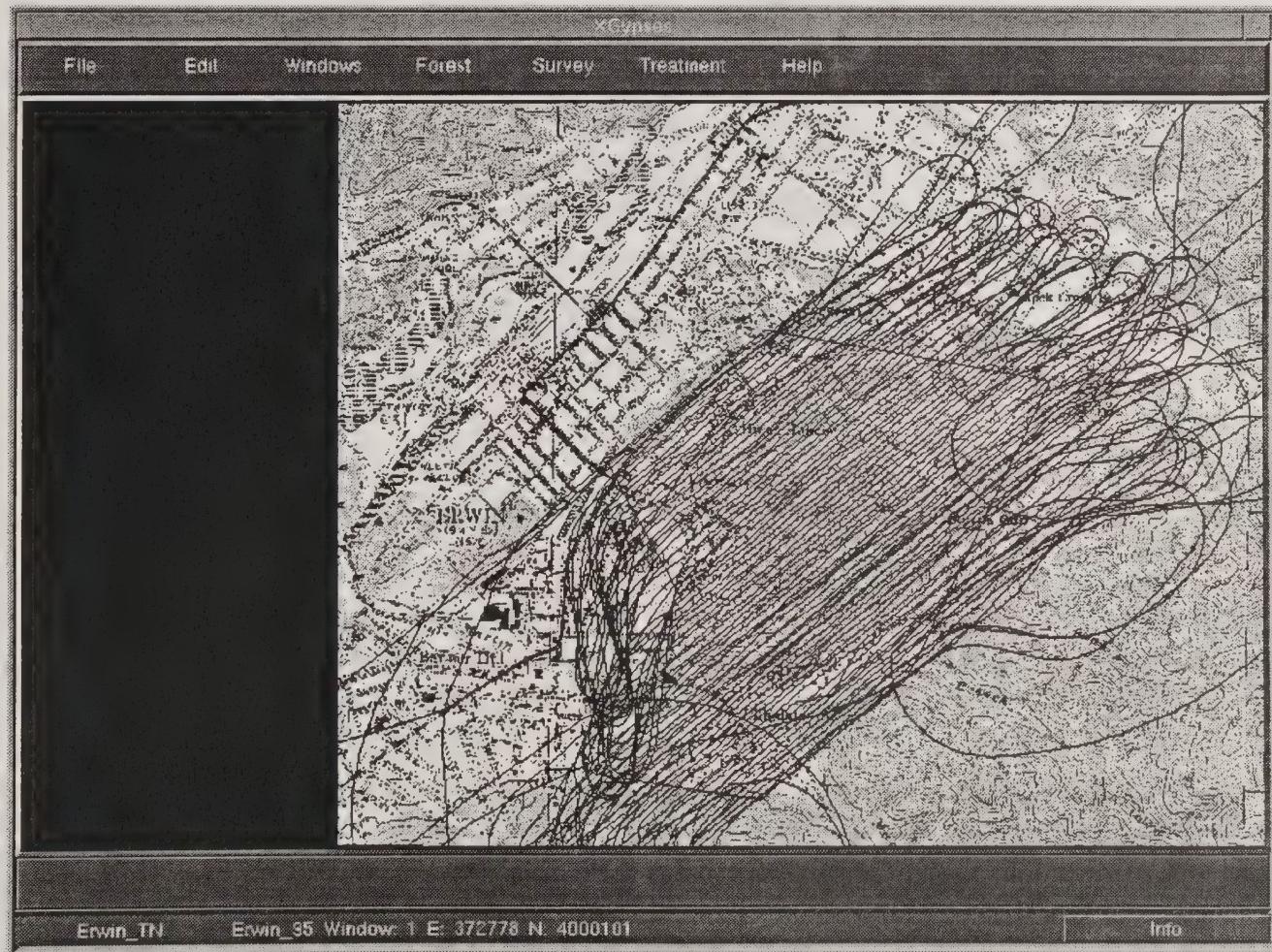


Figure 4. Erwin Tennessee 1995 Spray Project showing block and actual flight lines over quad backdrop.

the actual flight path of the aircraft is recorded and can be either monitored in real time or analyzed later. This function eliminates the need for a ground crew to mark block boundaries for the pilot and allows for immediate adjustment of flight plans, should on-the-ground or other situations necessitate such changes.

### **Accessing Functions via GypsES**

The above-described functions are represented on the interface menu as shown in Table 1. The GypsES menu system contains seven major pull-down groups.

**Table 1. GypsES Menu Group Functions**

<b>Menu Group</b>	<b>Description of Function</b>
File	Basic file control.
Edit	Editing data tables and spatial files. Many GIS functions are accessed here.
Windows	Control of display. Some GIS functions are accessed here.
Forest	Access to some integrated models, such as Hazard-rating and Stand-damage models. Used to perform overall analysis for project area.
Survey	Access to survey and monitoring functions.
Treatment	Access to treatment functions, including ability to import/export GPS files.
Help	On-line help system.

# Customer analysis

## Introduction

Users have had substantial input to the development of GypsES. User information is summarized in the following paragraphs.

## Current users

Users have had substantial input into the development of GypsES. The first prototype system was assembled and delivered to Prince William County, VA in 1992. Prince William County has been the main GypsES test site. Since 1992 the user community has grown to over 18, with most of the growth in 1995 and 1996. Most of the user agencies are state and county agencies. Some of the first systems (defined as the needed hardware, software, and dataset components that allow GypsES to function) were purchased by the GypsES development team to help show the uses of the system under real circumstances.

Table 2 on page 18 lists agencies currently using the system, the date the system was delivered, and the functions most used. See Appendix B, **User information**, for more detailed information about current users.

The development team indicated that if the Forest Service through the FHP staff discontinued its support and maintenance of GypsES, all users would stop using the system. This is true because of the complexity of the system as a PC-based UNIX configuration and because of the substantial effort needed to set up and maintain the required database. Most user-sites have modest experience in the use of personal computers but little or no experience in managing the UNIX operating system on this platform. In addition, the FHP staff provide a critical service in collecting and installing the site-specific spatial and attribute datasets so that they can be used easily by means of GypsES. Most sites have neither the expertise nor the staff time to deal with these tasks.

## Future users and potential customers

The user community is growing quickly; it will soon include the Animal and Plant Health Inspection Service (APHIS), which has ordered four systems, and the U.S. Air Force, which has ordered three systems. APHIS has shown great interest and sees the potential of GypsES for the management of other insects. With modest enhancements GypsES could become a general tool to manage many other defoliators such as spruce budworm and Douglas-fir tussock moth.

In general, any location faced with gypsy moth management issues is a potential user site for GypsES. As noted above, some users are beginning to experiment with the use of GypsES for managing other pests. For gypsy moth management, there will probably never be more than 100 user sites during any year, since there are generally not that many locations actively involved with gypsy moth suppression and eradication projects in any year.

**Table 2. GypsES Customer Analysis Summary**

User Organization	Date of Delivery	Product Functions Most Used
Prince William County, VA	June 1992	Mapping, egg mass survey and defoliation prediction, spray block creation, import and export of DGPS information, DBF to produce historic tree record
Forest Health Protection, Asheville Field Office	June 1993	Survey (suppression and eradication), map edit for treatment block design, treatment (FSCBG prediction, DGPS import and export), and graphic output for report writing
Forest Health Protection, Pineville, LA	April 1994	Survey, map edit and DGPS import and export, graphic output of topographical images with trap locations
Arkansas Plant Board (Arkansas Department of Agriculture)	1995*	Topographical maps, Digital Line Graph (DLG) files, Digital Elevation Model (DEM) data
Fauquier County, VA	April 1995	Egg-mass survey and defoliation prediction, spray block creation with export to DGPS, import of flight lines
Forest Health Protection, George Washington/Thomas Jefferson National Forest	September 1995	Survey (suppression) and defoliation prediction, DGPS import and export
Forest Health Protection, Morgantown, WV	September 1995	Spray block mapping
National Park Service, Capitol Region	September 1995	Survey (suppression), map edit to develop treatment blocks
North Carolina Department of Agriculture	September 1995	Map edit to create treatment blocks, survey (eradication mode) for trap placement, data recording
Tennessee Department of Forestry	September 1995	Survey (eradication), treatment for DGPS activities
Virginia Department of Agricultural and Consumer Services	September 1995	Survey and defoliation prediction, spray block creation, DGPS interface import and export
Ohio Department of Agriculture	May 1996	Mapping treatment areas and defoliation, defoliation prediction, connections to DGPS
Albermarle County, VA	September 1996	New user
City of Alexandria County, VA	September 1996	New user
Nelson County, VA	September 1996	New user
Orange County, VA	September 1996	New user
Indiana Department of Natural Resources	October 1996	New user; will be using pheromone trap survey functions
Wayne National Forest	Demonstration Project	Hazard rating and using the integrated stand damage model to forecast tree mortality

\* State regulations required ASPB to accept a competitive bid; the system purchased did not meet GypsES specifications. The GypsES group worked with the low bidder to correct the problems, but the sub-par components would not work with UNIX operating system. The State has since purchased another Gateway P5-166 system which is being set up to run GypsES. Currently GypsES data is collected on the Pineville Field Office system and will be transferred.

## **Nonusers**

Neither the New England states nor Pennsylvania use or intend to use GypsES. The New England states do not actively manage gypsy moth infestations. Pennsylvania, by means of suppression funds, has developed its own automated system for managing gypsy moth suppression and eradication projects. This system resides on a Sun Microsystems workstation and utilizes the ARC/Info™ GIS. Staff in Pennsylvania prefer to retain use of their own system rather than abandoning it in favor of GypsES. The authors are unsure of the depth of functionality of this Pennsylvania application or of the costs and reasons for maintaining it, but in all likelihood, the GypsES application has more functionality, since there are so many analytical tools integrated into it.



# Forest Health Protection benefits

The Forest Health Protection (FHP) staff of the USDA Forest Service traditionally takes a lead role in managing insect and disease problems on the nation's forests. Although FHP's mission has expanded recently to the more encompassing mission of protecting, improving, and restoring the health of the nation's forested ecosystems, insect and disease issues remain a critical and primary focus. Part of FHP's role in dealing with insect and disease issues includes managing the distribution of federal suppression funds to the states for use in insect and disease suppression and eradication projects. When one reviews various FHP planning documents, three FHP priorities that relate to GypsES stand out:

- FHP staff serve a critical and leading role in providing information and advice to the National Forest system, other federal agencies, tribes, state agencies, and other stakeholders so that they can make sound decisions about forest protection.
- Suppression and eradication treatments are shown to be economically, biologically, and environmentally sound.
- FHP staff provide technology that is efficient and environmentally acceptable, that meets customers' needs, and that results in healthy forests.

The U.S. government through the USDA Forest Service spends approximately \$1 million per year on gypsy moth suppression and eradication. This figure does not include the cost of federal salaries for the FHP specialists employed to assist state and county government entities in executing suppression and eradication programs. These dollars must be judiciously applied to gain the maximum benefit. GypsES was designed to help maximize this investment. Using GypsES has not necessarily reduced overall investment in gypsy moth suppression and eradication; rather it has improved the quality of suppression and eradication programs. By reducing costs of certain activities it has enabled the overall budget to reap larger benefits from more effective suppression and eradication activities. The benefits of GypsES described below are conveyed in terms of reduced costs of specific activities, better program coordination, improved quality, leveraging the application of proven gypsy moth management techniques, and generally improved program delivery.

The following paragraphs describe experiences to date on the benefits, both quantitative and qualitative, to users of GypsES:

1. Prior to the implementation of GypsES, design of sampling plans for the placement of pheromone traps had been a time-consuming task. This activity includes producing maps for use in designing the trap grid and then managing iterations of map changes to reflect changes in the sampling plan. Before GypsES, designing this trap placement plan for the Arkansas user on a 16,000 acre site would have required two weeks of staff time. The time needed for this task was reduced to two days using GypsES. As of 1996, this type of activity may be performed in Tennessee, Wisconsin, Arkansas, and North Carolina. The potential labor savings

across these sites is eight weeks. In addition, use of GypsES for this activity produces a better sample and thus better and more timely data for decision-making.

2. The trap database integrated within GypsES and used to store trap survey data has improved the quality of the trapping program on most user sites. This functionality within GypsES facilitates easy identification of missing trap data, and allows this information to be easily used when later defining spray blocks that will be treated with a suppression/eradication agent.
3. GypsES saves an estimated 20 percent in data handling time and produces better products in the course of preparing for, conducting, and analyzing egg-mass surveys. Egg-mass surveys are typically conducted from August through December of each year. Gypsy moth managers analyze the data and design spray blocks between January and March of each year following data collection. As an example, gypsy moth managers for the state of Maryland used to spend about 72 weeks of labor on these tasks. The use of GypsES has reduced this total by an estimated 14 weeks to 58 weeks.
4. The ability to electronically lay out spray blocks within GypsES, export these as GPS files for use in guiding aircraft during spray operations, and import GPS files showing the actual flight lines followed by the aircraft back into GypsES following a spray operation, has enormous cost and quality advantages over previous procedures. In Virginia alone, the cost of helium used in balloons marking spray block boundaries on the ground was reduced by \$50,000, since this new automated procedure eliminated the need for block identification balloons and the ground crew used to place them. In addition, the labor to prepare and place these balloons was eliminated. This new GypsES-related procedure increased spray operation efficiency by an estimated 20 percent. Efficiency was realized in ability to accurately spray the area intended and avoid spraying areas outside of the spray block. Efficient spraying means that the spray budget can be applied to spray more areas.
5. Use of FSCBG within GypsES on site to model spray drift under actual weather conditions allows immediate adjustment of flight plans.
6. Better spraying also has these hard-to-quantify advantages:
  - Improved professional image of the Forest Health Protection staff in the public eye.
  - Fewer complaints about improper spray operations, actual documentation of flight lines, and fewer law suits.
  - Potential of lower spray bids from contract pilots because GypsES facilitates more efficient spray operations by the pilot.
  - Improved contract performance by spray pilots because GypsES allows evaluation of flight line data showing where the aircraft actually flew.
7. GypsES serves as a vehicle for delivering other Forest Health Protection tools. The Forest Service has expended substantial funds on developing tools such as FSCBG. Yet these tools, for various reasons, have not been used as actively as they could be. FSCBG, the Stand

Damage Model, the Phenology Model, the Defoliation Prediction Model, Hazard Rating, and the soon-to-be-incorporated silvicultural guidelines represent useful analytical tools that are now being used as intended by gypsy moth managers because they are accessible through the easy-to-use GypsES interface. GypsES is extremely valuable in helping managers reap some benefits from these tools.

8. Related to item 6 is that GypsES is a vehicle for integrating relevant research findings into the decision-making process. A lot of research fails to get used. GypsES provides a vehicle not only to integrate research findings into the process but also to transfer the technology into practical use.

9. GypsES improves coordination of the gypsy moth suppression and eradication program.

- All data needed in administering these programs are located in one place.
- All analytical tools needed are in one place and configured to work easily with the required datasets.
- Forest Health Protection specialists can more easily work with local gypsy moth managers because operations facilitated by GypsES are consistent.

10. GypsES improves the quality and consistency of gypsy moth suppression and eradication programs. The system represents the best available knowledge and tools for managing this pest. In an arena where these programs span different states and localities with differing staffs and experiences, GypsES provides a consistent framework whereby each staff member has access to proven techniques and tools. The years of experience of Forest Health Protection specialists at the federal level and relevant research findings are available to every local manager through use of GypsES.

11. (This item is a comment rather than a benefit.) The GypsES development team indicated that were FHP to abandon GypsES and its end users, the result would be a credibility problem for FHP.

In summary, the quantitative benefits of GypsES to date indicate an expected 20 percent savings in traditional program costs. That figure translates to \$200,000 over a \$1 million suppression and eradication program if all sites used the product. These dollars are reinvested in the program to increase its effectiveness and scope. Non-quantifiable benefits are many and varied. They range from improved public relations to improved program delivery to improved mechanisms for putting research findings to practical use. GypsES seems to embrace the lead role that the Forest Health Protection staff of State and Private Forestry has in providing the best tools and knowledge available to the more local entities charged with carrying out gypsy moth suppression and eradication activities—GypsES is consistent with Forest Health Protection's traditional role of transferring technology and providing support to the field.



# Design issues

This section specifies the hardware and software used by GypsES and some of the issues that relate to why it was chosen. At the time that GypsES was first being developed the hardware and software needed to develop this type of application was not standard to the Forest Service or the counties that were looking for this type of application. Some of the functions that are implemented within GypsES are now common in off-the-shelf software packages, but were not available when it was developed.

## Software used in GypsES

Both commercial software products and public domain software were used to develop GypsES. Languages, libraries, toolkits, and user costs are also discussed in the following paragraphs.

### Commercial products

CodeBase™ 4.5. CodeBase™ 4.5, from Sequitur Software, provides routines to create and access dBase™ (.dbf) files compatible with dBase™, FoxPro™, and similar data bases. The license allows developers to link routines into a GypsES binary with no additional fees.

Developers chose this product because dBase™ files were the most common PC database at the time development started, and therefore users were more likely to have them. Lack of additional fees was also a deciding factor. CodeBase™ comes with C source code and can be re-compiled on another platform if porting is necessary.

### Public domain software

GRASS GIS. For accessing and manipulating GIS files, GypsES uses subroutines and shell routines from a product called Geographic Resource Analysis Support System (GRASS) that was, until recently, supported by the U.S. Army Construction Engineers Research Laboratory (CERL). The use of GRASS software is completely internalized in GypsES. No stand-alone access to GIS data using GRASS is available. The GypsES development team chose GRASS early on to avoid additional cost to users, as GRASS was the most extensive public domain GIS available at the time. The GypsES development team has all of the GRASS C source code, and can re-compile if porting is necessary.

TIFF library. GypsES uses routines in the Tagged Image File Format (TIFF) library to access TIFF image files. The 7.5 quad images in GypsES are electronic copies in TIFF format of 1:24,000-scale United States Geographical Survey (USGS) topographical maps purchased from Land Info, a commercial company. TIFF, a widely used image format, is a fairly efficient way to store and access image data. It is in the public domain and can therefore be included at no cost. The TIFF library comes with C source code and can be re-compiled if porting is necessary.

Routines ‘borrowed’ from the Internet. GypsES developers used certain public domain software routines downloaded from the Internet to shorten development time by providing convenient ways to design special types of widgets (controls in a Graphical User Interface [GUI], such as a window or a scroll bar) to initialize applications, and to handle color maps and the like. These routines both reduced development time and improved the user interface. The source code is C; it is portable.

## Languages

GypsES is coded entirely in C, using X-Windows, X-Toolkit, and Motif libraries. When the project started, an American National Standards Institute (ANSI) standard for C++ did not exist.

## Libraries

Libraries linked in order to create the GypsES binary are listed in the three preceding paragraphs. In addition to the TIFF Library, the usual C libraries were used.

## Toolkits

No toolkits or development aids other than those which are part of the software listed above are used in programming GypsES. The C compiler and linker provided in the Unixware™ development package are used for development. In 1991, when serious development of GypsES started, the development team looked for GUI toolkits and could not find anything flexible enough.

Developers use the standard UNIX Source Code Control System (SCCS) tool for source code control. All source code is checked out for modification and checked back in with a notation of what changes were made. If the change was a bug fix, the bug report number is noted, and the SCCS version number for each program changed is noted on the bug report as a cross-reference.

## User costs

The design of GypsES was driven in large part by the requirement that software costs to the end-user of GypsES be minimized. The software cost for a GypsES installation is the cost of the Unixware operating system, possibly the cost of a third-party X-Server, depending on the graphics board in the system, and the cost of the System Commander software that facilitates switching between UNIX and DOS/Windows.

Current pricing is as follows:

- |                            |                   |
|----------------------------|-------------------|
| • Unixware Run-time        | \$440 (old price) |
| • X-Server (Accelerated X) | \$150             |
| • System Commander         | \$100             |

The purchase of Unixware™ by Santa Cruz Organization (SCO) has resulted in almost doubling the price of Unixware™ in the last year. The GypsES development team is exploring alternative Intel UNIX sources and/or a port to the Windows environment.

The effort to minimize software costs to end-users has to some extent been successful in that GypsES does not require commercial products like ArcView™ or ArcInfo™ which together total at least \$2,000 for the microcomputer platform. However, the effort to save on software costs resulted in a highly customized system running on a PC-based UNIX operating system. This configuration dictates the use of specific microcomputer brands with specific internal components and related hardware. In order to use GypsES, virtually all sites must buy this hardware, since it is unlikely that their existing microcomputer equipment is sufficient. Many of these sites would have been buying new equipment anyway, so purchasing the needed brands was not a problem. But some sites bought the equipment solely to support GypsES. Thus, the anticipated savings on software, in some cases, was instead spent on hardware.

For some new users, an additional cost incurred because of the system requirements of GypsES is the cost of setting up and implementing the system, since they are paying for this service. Because of the specific hardware requirements and other configuration issues, development team personnel in Morgantown normally handle procurement and setup of the hardware. It is highly unlikely that staff at a user site could handle implementation of GypsES on their own. This task is fairly labor-intensive. Two microcomputers of the same brand and model may actually have different internal components, and GypsES may work on one but not the other. To set up and test the hardware, install the software, and build and install the needed datasets for one system can easily cost from several thousand to almost ten thousand dollars in labor.

Most, if not all, current users are not paying for maintenance costs (these costs are currently covered by the GypsES budget). However, if users must cover these costs in the future, maintenance will represent a significant component of GypsES user costs, since ongoing maintenance is necessary in order to keep abreast of hardware changes as well as other issues. A large share of these costs is caused by the highly customized nature of GypsES.

GypsES user costs are composed of four components: software costs, hardware costs, setup and delivery costs, and ongoing maintenance. Although software costs are modest, the total cost of all four components can be substantial. Consideration of options for delivering GypsES functionality through commercial products or the existing method should consider not just software costs, but all costs.

## Data structures

GypsES stores information in flat files and dBase™ (.dbf) files. GIS data is stored in GRASS-compatible formats. This includes raster, vector, and site (point) data. Image backdrop data, such as quad images or SPOT images (SPOT is *Système Probatoire d'Observation de la Terre*, a system of two French satellites; SPOT is an industry standard) are stored in TIFF format.

The dBase™ file format, as explained above, was chosen because at the time the project was initiated it was commonly used on PCs; therefore, users would be most likely to have information in that format. Some information is stored in flat files for ease of maintenance.

The GRASS data format is used because GRASS was free and was well maintained. The TIFF image format was used because the quad data came in that format, because TIFF is public domain, and because there are no problems in using it or obtaining the libraries to access TIFF files.

GypsES also supports the creation of Differential Global Positioning System (DGPS) files. Although these files are not used by GypsES directly, these are created by GypsES for import into GPS systems on aircraft to support spray operations.

## Product issues

### System functions

GypsES uses the GRASS file I/O routines to access GRASS data structures. GypsES also uses a small subset of the GRASS executable routines for file maintenance and file manipulation. The layer display capability in GypsES is strictly GypsES code, using standard X-Windows library routines.

### Commercial product alternatives

ARC/View™ was not used because it was not available when the development was begun; because of its cost and limitations, it is still not considered a viable alternative.

### Lines of source Code

GypsES source code is currently about 183,000 lines, not including the CodeBase, GRASS, and TIFF code. It is all C code.

### Disk Space Usage

The GypsES development directory, including source and object code, link libraries, TIFF and CodeBase™ takes up about 26 megabytes (MB). This does not include the GRASS source and libraries or various code written to convert GIS files to GRASS format and to transform image files.

The space used by GypsES when installed, including all system files and executables and a demonstration database, takes up about 65 MB. The GypsES executable binary is 3.35 MB.

Disk usage by GIS files is dependent on the size of the land areas represented in the spatial files, quantity of information (images, raster, vector files), and extent of historical data. (Gypsy moth data is kept by year). For example, the Prince William County rectangle contains approximately 870 square miles. The "PERMANENT" map set, containing elevation, roads, hydrology, quad images, and SPOT Images takes up 150 MB. The size of a single year's data, depending on spray blocks, lines, and egg-mass survey information, might take up 10 to 20 MB.

GypsES frequently makes copies of files so that they may be restored if the user wishes to close the session without saving changes. GypsES deletes these temporary files when the session is

finished. Graphics output files are routed through the UNIX line printer print spooler, and can be quite large for high-resolution devices when larger-size maps are produced. One hundred to 150 MB of root file system space should be free to handle these files.

To summarize, the Unixware™ operating system (OS) needs about 200 MB of disk space. GypsES as installed needs about 65 MB. To allow for "PERMANENT" and yearly data for a location the size of Prince William County and about ten years' worth of data would require 350 to 400 MB. Additional temporary files require 200 to 350 MB. So, a Unixware™ partition for such a location (county) would need a minimum of one gigabyte (GB) of disk space. GypsES designers recommend two GB of disk space in order to allow for additional GIS files and a DOS/Windows partition.

## **Hardware/operating system**

### **GypsES hardware requirements**

GypsES runs on machines with the Intel™ processor running the Unixware™ OS. The processor recommended is a Pentium™ with a minimum of 32 MB of RAM. The Unixware™ OS does not run with all devices, so Dave Breakey of the GypsES team oversees the procurement of hardware and works with the users to insure that the hardware purchased will work with Unixware™. Besides the two GB of hard disk space recommended, GypsES requires a Small Computer Systems Interface (SCSI) for CD-ROM and digital audio tape (DAT). A 17-inch monitor (minimum) is also recommended.

GypsES has been successfully installed on laptops that can support the X-server at (minimum) 800 X 600 pixels resolution with 256 colors. These units typically have disk capacity in the 0.8 to 1.2 GB range. Docking stations provide interface to tape and CD-ROM peripherals.

### **Porting**

A port to another UNIX OS presents no insurmountable problem but would require about six months of programming time to complete. A port to Windows NT™, which has been discussed by the development team, would present a number of challenges, not the least of which would be maintaining a single set of source code for both UNIX and Windows NT™ versions. Over time, if GypsES were ported to NT™, the best tactic would be to abandon the UNIX version so that only one set of source code would be maintained. An existing software package called Nutcracker™, which produces a Windows Application Programmer Interface (API) from a UNIX-based system, is a possibility, but the feasibility of using this package is not certain at this point.

### **Compatibility with USDA Forest Service 615 systems**

The development team has successfully transferred National Forest Oracle™ data to GypsES using the Oracle™ report generation facility. C programs have been written to read the report files and import the data into GypsES dBase™ and flat files.

The intent of transferring National Forest data to GypsES was to provide information to a GypsES user. GypsES does not provide a facility to modify the Forest Service database in any way. Developers anticipated that periodic downloads to the GypsES database would be made from the “corporate” system to refresh the GypsES system.

GypsES can read and create GIS layers using the .dxf image format, so GIS data can be transferred between 615 ARC/Info™ files and GypsES. Again, the primary flow would be from ARC/Info™ to GypsES to create the base layers used by GypsES.

## **615 Standards and Port**

GypsES was designed and intended for state, county, and private customers. Standards related to the FS corporate system were not a consideration. A port to 615 AIX (IBM’s version of UNIX) would not be difficult to provide, but at this time there is no user demand for it. However, regardless of porting difficulty and demand for the product on 615, probably the biggest issue and potential roadblock are Forest Service policies established by Information Systems & Technology (IS&T) and interpreted by regional management systems staff. For example, because GypsES includes some GIS functionality and stores data in .dbf files, those responsible for managing 615 systems in each region may rightly block any attempt to run GypsES on 615. Although standards and policies toward 615 are still evolving, there are some contract restrictions which preclude installing products on 615 which appear to compete with existing commercial software already on the system. The full ramifications of these issues will not be evident until a real effort to install GypsES on 615 is attempted.

# **Standards adherence**

Several different standards are typically recommended that could be followed during software development. Most Forest Service software does not follow all of these standards. This section discusses the extent to which the GypsES development team followed these standards.

## **Life cycle management**

Although developers of GypsES did not use a structured, life-cycle management development process, they used a number of development methods in the evolution of this product. The system development team performed an analysis and evaluated users' needs. The team wrote design documents during development, and all members of the development team reviewed all design features.

## **Language standards**

The C code meets the ANSI standard.

## **User interface**

The user interface uses the X-toolkit and Motif™. The look and feel of the interface is not internally consistent at this time because the original interface was written using Athena™ widgets, and later additions used different widgets. The code is being converted to use only Motif™ widgets.

## **Operating System, GIS, and Database**

The software was developed and is delivered on Novell's Unixware™, which is a System 5, Release 4 (SVR4) standard version of UNIX. The C compiler used comes with the UNIX operating system. The data formats for the GIS information are GRASS version 4.0, and the backdrop files are in TIFF standard format. The database information is stored in dBase™ file format. Other data is stored in American Standard Code for Information Interchange (ASCII) flat files.

## **Forest Service standards**

The product will not currently run on the 615 platform; there has been no need to port it to that platform, because almost all current customers are states and counties. Since GypsES software is made up of custom code and libraries for which the developers have source code, there should be no major obstacles to porting the software as is should the need arise, assuming approval from Information Systems and Technology staff (IS&T). If the software were ported to the 615 platform developers would use the 615's AIX C compiler and the Motif™ libraries on the 615 system. Unless there is a major rewrite of the product, the database files will not be converted to

Oracle™ (the database used on 615); nor will ARC/Info™ (615's GIS) file formats be used. If GypsES were to be ported to the 615 platform, all data needed by GypsES that is now stored in Oracle™ tables and in ARC/Info™ file formats would need to be transformed into the formats used by GypsES.

The issues and policy constraints that will affect approval to install this software on the 615 platform are as follows:

- GypsES does not use corporate commercial software such as Oracle™ and Arc/Info™.
- Some GypsES GIS functions might compete with Arc/Info™ as a GIS tool. (This may now be solely a policy problem rather than both a policy and a contractual problem, since the Forest Service now owns an unlimited license to ArcInfo™.)
- Porting GypsES to the 615 platform will require storing duplicate sets of data while a project is ongoing.

# Software documentation

This section reviews the status and quality of documentation available for GypsES. Documents that were not available but that are common components of major software products are discussed at the end of this section. Documentation is an important component of software, since it influences not only the ability of users to use the software easily but also their ability to maintain the software efficiently over time. Good user manuals reduce support costs; with them users are less dependent on support from the development/support staff. Also, good systems documentation facilitates program maintenance, particularly when staff turnover occurs.

## Design documents

There are multiple design documents for the software. Three universities—Pennsylvania State University, West Virginia University, and Virginia Polytechnic Institute and State University—originally worked on the product. They developed a design document during the first three years of the project. After the universities were phased out of the project in 1992, the staff at the Northeast Forest Experiment Station assumed responsibility for further development and maintenance. They have created hard-copy design documents for each function added or redesigned. These design documents, which were written and reviewed by the development team for use by the programmers, vary in amount of detail. Some are illustrated by hand-drawn sketches of screens; others have illustrations prepared with a graphics package. The documents include information about how the program should function based on user responses to the interface. These documents are not currently organized and kept in one central location.

## User's Manual

The original User's Manual was well written, with plenty of graphics and indices so the user could find information fairly quickly. However, it is outdated. Both the software interface and functionality have changed dramatically since the manual was written in 1994 and 1995. In fiscal year 1996, the development team elected to focus its resources on development of a fully operational version of GypsES rather than on producing a new User's Manual. The development team plans for a technical writer to work on a new User's Manual half time in fiscal year 1997. A justification for a good User's Manual is that GypsES, rather than being used year-round by the end users, is used during the time that suppression activities occur—from spring until late fall. End users usually need advice on getting started with GypsES after being away from it for a few months. In addition, users need different GypsES functions at different times of the year. Functions used in the spring may not have been actively used since the preceding spring. Finally, turnover among end users is not uncommon from one year to the next. New users usually do not have access to other staff members onsite who are familiar with the system, since only one or two persons are familiar with GypsES at any one site.

## **In-line coding documentation**

Source code files contain a moderate level of in-line documentation. There is header documentation at the top of each module (source code file) which lists the functions in the module and their purpose. There is, however, no header documentation with each function. A majority of the variables have documentation that explains what they are, but this documentation is not complete throughout the code. Each module should have a revision history section in its header. Although, in general, the in-line documentation is good, some places in the code need more documentation.

## **On-line help**

The system includes a simple on-line help system. The on-line help does not include hypertext links and is at this time very out of date. During this review, the Enterprise Team staff discussed the possibility of implementing this type of help system using html files and accessing those files with a public domain internet browser like Mosaic. This implementation tactic may be a faster method to build help files and provides more robust help facilities.

## **Tutorial and other learning aids**

There are currently no tutorials or similar learning aids, but there is a plan to write a tutorial within the next year. The development team has given the tutorial a higher priority than the revised User's Manual. Note that all site datasets are pre-loaded, so there is no need for sample datasets. There are no plans to produce videos or slide packages for training.

## **Documentation not available**

### **Requirements specifications**

Scattered information is available on what was planned for the system when the GypsES project was initiated, and planned enhancements are documented. However, these documents are not detailed enough to function as a requirements document. The development process was iterative in nature—a process frequently referred to as “spiral development”. Developers made a prototype of the initial concept, gleaned feedback from pilot sites, developed more prototypes, and so on. Eventually, through these iterations, they produced an operational version. There is no plan to complete a requirements document.

### **Test specification**

There is no test specification for GypsES, and there is no plan to complete one.

## **Installation/Systems reference manual**

GypsES has no installation or systems reference manual. The development team is not particularly concerned about lack of a manual, since the system is delivered as a turnkey system to the end user. The development team configures all hardware, loads all software, and prepares and loads all datasets prior to delivering the system to a site.



# Testing and error handling

Good pre-implementation testing and debugging, as well as error handling routines embedded within the software code, give end-users confidence in the product and reduce maintenance problems and costs.

In the software industry, major software development efforts usually include formal test plans and rigorous error trapping routines. There are commercially available software testing products that cost thousands of dollars. Some companies have specialized staffs whose sole purpose is to test software. However, because of budget constraints, many software development projects in the Forest Service as well as other federal agencies conduct much more modest efforts to test software and build in error-trapping routines.

The GypsES development history is similar to that of many other Forest Service development efforts in that testing was more informal than on some major software development efforts. Testing procedures consisted of programmers themselves testing their code, and, upon implementation of the program on test sites, getting further feedback on bugs and other system weaknesses from test-site users. Like most software developed in this manner, early beta versions included a fair share of bugs, and the initial users of the software served a major role in locating these problems. Until recently, it was not uncommon for the system to "crash" periodically when used in a moderate manner by end-users. However, in the last six months the developers have been able to eliminate the majority of these problems, and the software appears to be quite stable relative to what one would expect from a version 1.0 software release.

Software debugging and error trapping has consumed a fair share of the development team's time in the past year or two. Given the size and complexity of the GypsES program and the number of programmers actually devoted to this project, this is not unusual. However, future plans for support and maintenance of the product should reflect on this experience, and be funded accordingly. It is not uncommon for software projects of this nature to miss deadlines for enhancements and new features because debugging and error-trapping tasks demand attention.



# Development history in terms of cost

The source of funding and the amount funded have changed over the years. This section describes the source of the funding and the allocation of those funds.

Until 1991, virtually all the funds coming to GypsES came from Gypsy Moth Research and Development (GMR&D) funds, and were distributed to Pennsylvania State University, West Virginia University, and Virginia Polytechnic Institute and State University. In 1991, Technology Development Project (TDP) funds were added to GMR&D funds and the universities were phased out. Beginning in 1992, the Northeastern Forest Experiment Station contribution has been \$60,000 for the salary of the lead programmer. After 1992, all funds were used to build an internal development team and begin field testing. The development team says that funds will need to stay at the same level for the next three to five years to continue to support this product and add enhancements. The history of GypsES development costs is summarized in Table 3.

**Table 3. GypsES Development Cost History\***

Year	Budget	Source	Where spent
1988	\$80,000	Northeastern Forest Experiment Station	100% Analysis and design
1989	140,000	Northeastern Forest Experiment Station	100% Analysis and design
1990	175,000	Northeastern Forest Experiment Station	100% Analysis and design
1991	196,000	State & Private Forestry	100% Analysis and design
1992	196,000	State & Private Forestry	50% Analysis and design 50% Development
1993	160,000	State & Private Forestry and Northeastern Forest Experiment Station	20% Analysis and design 80% Development
1994	160,000	State & Private Forestry and Northeastern Forest Experiment Station	20% Analysis and design 80% Development
1995	130,000	State & Private Forestry	20% Analysis and design 50% Development 30% Implementation/support/maintenance
1996	130,000	State & Private Forestry	20% Analysis and design 50% Development 30% Implementation/support/maintenance
1997 estimated	215,000	State & Private Forestry and APHIS	20% Analysis and design 30% Development 50% Implementation/support/maintenance

\*The GypsES costs shown in this table do not include funds used to pay selected Federal salaries (shown in Table 4.) Funds for these Federal salaries came from either the staff's base budget or from Northeastern Research Station funds.

In fiscal year 1997, the budget will be allocated as follows: 50% of the work will be on analysis/design/development, and 50% will be spent on implementation, maintenance, and user support.

The USDA Animal and Plant Health Inspection Service (APHIS) is interested in the product and will contribute \$65,000 for modifications and support. When APHIS contributes the necessary money, the development team plans to add another programmer. Thus the total FY 1997 budget will be \$215,000. Most of this total is derived from APHIS, the Northeast Area Forest Health staff, and the Southern Region Forest Health staff, each of which will contribute \$65,000.

Allocation of staff time for the GypsES project in 1996 is summarized in Table 4.

<b>Table 4. Staff time spent on GypsES in fiscal year 1996</b>			
<b>Name</b>	<b>Task</b>	<b>Percentage of full-time staff position</b>	<b>Source of funds</b>
Dan Twardus	Management	33%	FHP staff base budget
Kurt Gottschalk	Management	5%	Research staff base budget
John Ghent	Management, Design, User	60%	FHP staff base budget
Amy Onken	User support	20%	FHP staff base budget
Susan Thomas	Programmer - Development	70%	Research staff base budget
	Programmer - Implementation & user support	30%	
Doug Mason	Programmer - Development	93%	GypsES budget
	Programmer - Implementation & user support	7%	
Anne Cumming	Data development & acquisition	50% (half-time employee)	GypsES budget
Dave Breakey	Hardware and system setup - Implementation and user support	100%	FHP staff base budget

The GypsES development team projected that recent funding levels must be maintained for at least the next several years in order to continue with enhancements, perform software maintenance activities, and minimally keep up with implementation and support for the growing list of end users. This projection seems reasonable to the Enterprise Team review team, given the complexity of the software and the level of support provided to end users.

# Implementation, system administration, and maintenance issues

There are many issues that pertain to the implementation and day-to-day maintenance of a software package. General issues discussed in this section include installation, training, user support, routine system administration, version control/upgrades, effects of changing technologies, and enhancements.

## Installation

The GypsES software is delivered to the user as a “turnkey” system; that is, when the user turns on the machine the hardware, software, and data are highly customized, loaded and ready. GypsES is installed on Intel™-based PCs running the Unixware™ operating system. Unixware™ is a version of UNIX developed by Novell and recently purchased by Santa Cruz Operation (SCO). A software package titled System Commander™ is also loaded so that the machine can be started with DOS/Windows™ as the operating system. This configuration allows users to use the machine for other software packages besides GypsES. The major reason that the software is delivered as a turnkey system is to prevent configuration compatibility problems with the hardware and operating system. It is much easier for the GypsES development team to order the proper hardware and configure it than it would be if users tried to do it on their own. In fact, given the complexity of the GypsES system and the typical skill level of the user-site personnel, it may be totally unrealistic to ever expect these users to procure and install the components of this system on their own. Once the system has been installed, users do not have many problems with the system. GypsES was developed on the UNIX platform because of the use of GRASS as the GIS software. UNIX also made development easier because of memory requirement problems of DOS.

The hardware is sent directly to Dave Breakey of the GypsES development team, who is in charge of hardware and system setup. It takes Dave one to three weeks to install and configure the hardware and operating system. This job requires someone with hardware and UNIX system administration skills. The major reason for the configuration time is hardware compatibility issues with Unixware™. Unixware™ requires specific SCSI cards, graphics cards, tape drives, and the like. It is not uncommon for computers ordered from the same vendor to contain different internal parts, some of which are not compatible with GypsES. After Unixware™ is configured Dave loads the GypsES software.

After GypsES is installed, Anne Cumming, Data Development and Acquisition Specialist, loads the data. It takes Anne one to five weeks to put together the spatial data. This job requires someone with GIS skills. Anne orders the digital maps and manipulates and organizes them

electronically so that they can be viewed seamlessly with GypsES. She also links any other data layers that the user provides. After Anne installs the data she tests to make sure that everything is displayed properly, and then the machine is sent to the user.

The decision to deliver a turnkey system rather than expecting users to install GypsES eliminates numerous problems with installing a complex system. Providing this service also represents a large investment in staff time by the Forest Service.

## **Training**

GypsES training sessions were held in September 1995 and September 1996. Another session is planned for February 1997 for APHIS. Training sessions, held at Morgantown, WV, last about two days; they are conducted by Susan Thomas, John Ghent, Amy Onken, and Doug Mason. Amy Onken also does onsite training, usually staying one week. In most cases one person at a site is trained. In the future the GypsES development team would like to phase out the use of programmers for training in favor of regional contacts. Also they would like to develop a tutorial in 1997.

## **User support**

GypsES is only used seasonally; therefore several months pass between occasions for using the software. When users use the software after a lapse of some months, they call two or three times a week for the first couple of weeks and then about once a week. Users call John Ghent, Amy Onken, Susan Thomas, or Dave Breakey for support. Neither the volume of calls nor the type of questions asked is tracked or documented. The questions are usually fairly simple, and most could be answered by a user's guide if one existed (in the opinion of the development team). User support needs are highest in spring and summer.

The GypsES user support staff use a bug report to track all bugs called in by users.

## **Routine system administration**

GypsES has a button to click to activate upgrade procedures when a GypsES upgrade tape is sent out. Another button activates a backup procedure. The UNIX operating system has not been upgraded. Such an upgrade would probably be at least a six-month job for Dave Breakey. As more users are added this job will take even more time. Dave Breakey is called for all system administration questions and for trouble shooting both hardware and software.

## **Version control/upgrades**

The development team has labeled the most current version of GypsES as Version .95. New versions are not released to all users. Upgrades are sent only to people who are affected by the changes. At this time only the Virginia Department of Agriculture and Consumer Services has version .95. At the September 1996, training session the GypsES team plans to use version .96.



**Figure 5.** SPOT image of Mason Neck. Shows park boundaries and egg-mass survey sites, color and symbol-coded for density.

At that time they will send out an upgrade for all users. Developers started with version .9 in September 1995, and produced six upgrades in 1996. Some recent upgrades were done to allow:

- The use of SPOT maps to display as backdrops (See Figure 5).
- The ability to create DGPS files for in-flight GPS support.
- The ability to run FSCBG with a user-friendly interface.

Currently the lead programmer changes the version number when she thinks there has been a significant change. In the future, developers plan to put out quarterly updates.

Source Code Control System (SCCS) software, which comes as part of the UNIX operating system, is used for version control. When changes are made to the code based on bug reports or change reports, the SCCS comment section is used to refer to that report.

## Effects of changing technologies

Instability in the market for UNIX operating systems for the Intel™ processor might make porting the application necessary at times. It takes one person at least six months to port the

application. Although the GRASS GIS software is no longer supported, this lack of support has no effect on either GypsES or its ability to be ported. However, printer and plotter drivers and utilities for DGPS must continue to be written as new printers and plotters come on the market. It takes from two hours to three days to create a driver; this task can only be done by programmers who are intimately familiar with all the hardware and software used in the GypsES system. The advent of notebook computers that can support Unixware™ and requests from users to use notebooks have increased the complexity of dealing with hardware configuration. These changes and their impact on the development team's time can be expected to continue. Thus, resources needed to deal with these issues are substantial and not likely to dissipate.

## Enhancements

The ideas for enhancements come from various sources:

- John Ghent, Dan Twardus, and Kurt Gottschalk.
- End users.
- Other developers such as Milt Teske and Jack Barry.
- Research.

Many of the ideas for enhancements come from John Ghent. As an end user as well as one of the developers, he has unique insight into what is needed. John Ghent, Dan Twardus, and Kurt Gottschalk prioritize the enhancements. One of their priorities is to continue to do technology transfer from research. Recent enhancements have been an important factor in the adoption of GypsES by some users. The eradication enhancement was a critical factor in the decision of the Tennessee Department of Forestry to use GypsES. The U.S. Department of Defense became a GypsES user primarily because of the DGPS enhancement and the integration of the FSCBG model.

# **Future development plans**

## **Identified and scheduled enhancements**

This section contains a list of enhancements to GypsES which have been identified by the GypsES development team and scheduled for programming or development of specifications in FY 1997.

### **Graphics output drivers**

Although GypsES can output to a variety of graphics output devices, new devices have replaced them in the last year. Although in many cases the old drivers will work with the new devices, they cannot not take advantage of higher resolutions and other features. This project, expected to take one-and-one-half to two weeks, will provide users with more choices in graphics output devices. This is an ongoing issue because hardware is seldom, if ever, delivered with drivers that can work with GypsES systems.

### **Zone consolidation and error checking of quad image data**

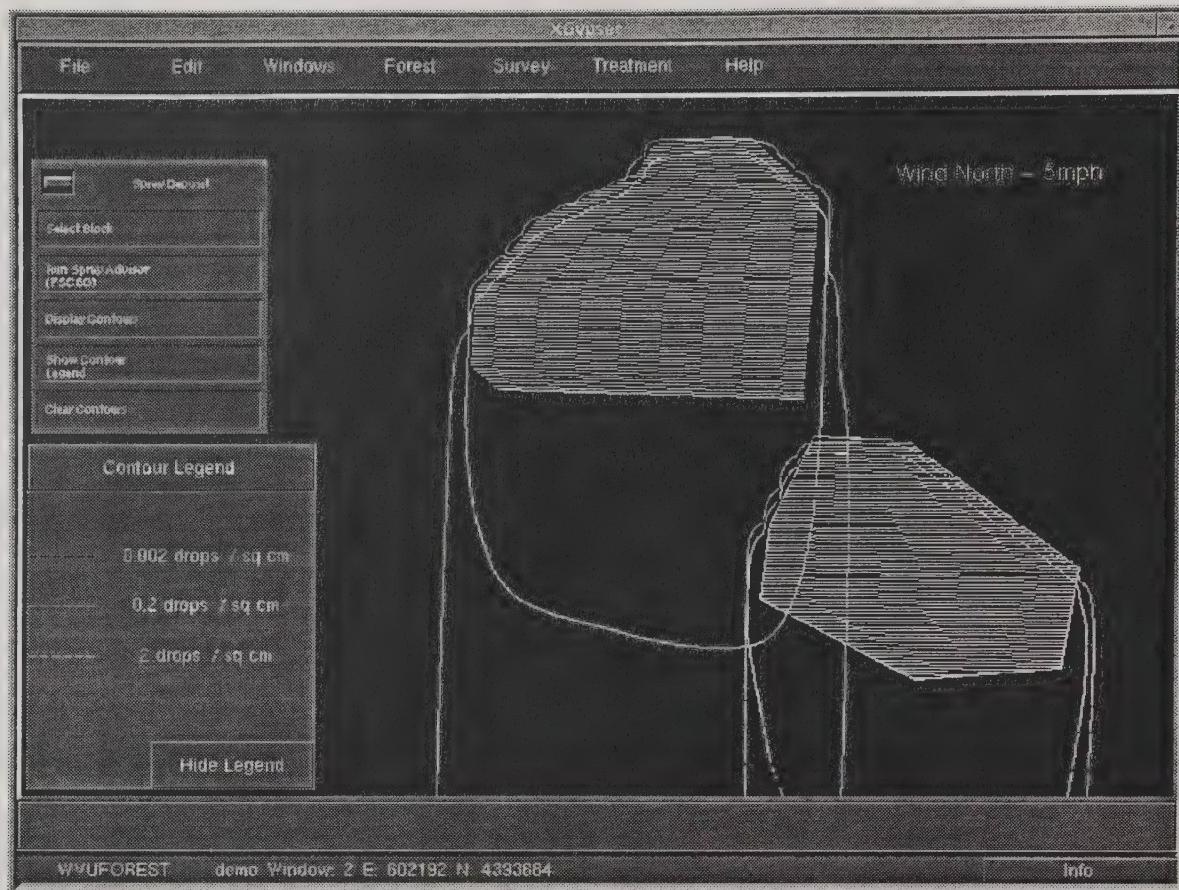
Users have encountered problems with quad image data when contiguous areas are ordered from Land Info at different times. The effect on the user is that areas of white show up instead of the 7.5 minute quad image. Developers plan to modify the import program to identify and correct these problems. Additional problems arise if a location spans two Universal Transverse Mercator (UTM) zones. Solving these problems will take four to seven days of programmer time.

### **Stand damage interface**

Modifications required to handle processing to support the Wayne National Forest project include generating a database of the Damage Model results in dBase™ format so the results may be summarized using standard PC software. This effort should take three to five days of programmer time; this phase of development will take place when the database requirements are defined, probably in the September and October 1996.

### **FSCBG deposition grid & spray accountability**

Currently, FSCBG output includes spray deposition contour lines which may be displayed and retained in GypsES (See Figure 6). A revision of FSCBG, expected this fall, will provide a deposition grid so that GypsES will be able to calculate a raster surface layer which can be used to calculate cumulative deposition, and, ultimately, used in rulebase operations. These changes will require two to four days of programmer time, depending on how FSCBG presents the information.



**Figure 6. Spray blocks with flight lines and FSCBG-generated spray density countours.**

### Archive/restore by location/mapset

Developers plan to add an option to the GypsES File Menu to allow archiving and restoration of Locations, Mapsets, or individual GIS layers for export/import to other GypsES systems. This function will be important in states such as Virginia, where data must be shared between systems. This enhancement will take three to five days of programmer time.

### Revision of .dxf import/export

Currently a GRASS routine is being used to import .dxf files. The capability is very limited and does not provide options for layer selection and naming. Site files are not supported, and polygon labels can't be imported properly. Since the .dxf import/export capability is key to the ability to interface with other GIS systems, a revision is necessary. This enhancement will take three to five days of programmer time.

### Revisions to GypsES interface

Many GypsES screens retain the boxy look and feel of the original Athena™ widget set and do not take advantage of the more advanced Motif™ interface tools now available. Revising the screen appearance will not only provide a more consistent interface for users, but also improve

GypsES performance by limiting use of X-Server memory. This project can be broken down into several small "filler" jobs which can be done as time permits. The total time required is six to seven programmer weeks.

### **Provide additional database/reporting functions**

Users have indicated a need for the means to create a data base within GypsES and for a capability to generate reports from GypsES data base files. Although some code for these functions exists, it is incomplete and must be reworked. Estimated time to add these enhancements is two to four programmer-weeks.

## **Projects to be defined and prioritized**

The following projects have not been defined sufficiently to estimate the programming time required. This does not necessarily mean that the items listed above will be completed before addressing those listed below. The GypsES development team will set priorities and decide on the sequence.

### **Treatment monitoring database link**

To minimize the data entry requirements for GypsES, systems developers will provide linkage from GypsES spray block information to the treatment monitoring database used by FHP and the State Cooperators. Some basic design work must be done to determine specific steps for this project.

### **Link with Southern Region Continuing Inventory of Stand Condition (CISC) files**

Ann Cumming, Data Development and Acquisition Specialist, will be identifying differences and similarities of fields needed for hazard and stand damage. A conversion/import program will probably be needed.

The goal is to develop data base/GIS information which can be merged with other information for the area. Forest planners would like to use GypsES in a cooperative effort between the Cherokee National Forest and the State of Tennessee to eradicate gypsy moth.

### **Silvicultural options**

This enhancement represents a transfer of research technology. Kurt Gottschalk has developed a set of silvicultural guidelines which suggest ways to minimize gypsy moth damage. Specifications are being developed to define what data is needed and to determine how a rule base can be used to provide this type of decision support as part of GypsES.

## **Use 1:100000 /1:250000 for image full view**

To enhance the usefulness of GypsES image information for users, developers plan to use 1:100000 or 1:250000 map images to allow the user seamless “zoom-in” capability from geographic views too large to see detail in the 7.5 minute quad and spot images. This larger-scale image information can be acquired quite inexpensively; however, it may require additional programming to bring into GypsES standard TIFF format.

### **Roll-up options in legend area**

Users have indicated a need to make the frequently-used functions of GypsES more quickly available by placing easily-selected “roll-up” windows in the work area space currently only used for raster file legends. “Hot Key” capability for commonly used functions would also enhance usability. Accomplishing these goals will require a major interface redesign.

Because the project requires further design, developers could profit from more user input. A preliminary design document could be either circulated or presented at a user meeting or training session.

### **Surface generation improvements**

To make certain model applications (such as defoliation prediction) more credible, developers propose to modify the GypsES surface generation program. After modification, interpolation on a restricted, user-specified area surrounding a given point would allow surface generation based on linked database values. It would also be possible to track the tie to the database so that the system would warn the user to regenerate the surface when the database changes.

### **Multi-location consolidation interface**

State coordinators would benefit from the ability to consolidate certain types of data (egg-mass counts, trap-catch data, spray blocks, and the like) into an “umbrella” location which represents the entire state. Creating this capability is a complex task because it will require pulling information from multiple UTM zones, and because the “flattening” of such a large area will introduce some distortion into area and distance calculations.

### **GPS up/down load**

Capability to upload and download point data from GypsES would increase usability for GPS field work. To accomplish this, GypsES would first need to be able to upload point (site) data to a diskette for transfer to a GPS unit such as Trimble™. Second, GypsES would need to be able to download point (site) data from a diskette created by GPS software on a PC. There would have to be some capability for the user to specify the content of the data string associated with the point coordinates so that a data base file could be built. (John Ghent currently compensates for this GypsES limitation by converting the downloaded information to a .dbf file on a PC and importing it.) Third, GypsES needs the ability to download points from a GPS unit and use the points to build a vector (line) file layer.

There are also other needs in this area. Although there is a stand-alone program to handle the first problem and a work-around for the second problem, there is no solution available for the third problem.

### **Mapset-level locking**

As the system currently allows the user only one GypsES session at a time on a machine, a mapset-level locking modification is necessary to enable the user to run multiple versions of GypsES from a single machine.

### **Change Location default view/delete location.**

Since the GypsES GIS Specialist “clips” image data when she sets up data for a location, a change (enlargement) of the default view will result in areas for which there is no image or line data. Although there are work-around procedures outside of GypsES to accomplish both of these functions, providing the capability to perform them in GypsES would enhance its usability.

### **Import of ARC export (.E00) format**

Currently file transfer procedures are more complex than they need to be. The GypsES development team will try to get the ARC export data file format from Environmental Science Research Institute, Inc. (ESRI). This will simplify file transfer.

### **Phenology**

To make the phenology modeling much more accurate and to facilitate phenology calculation for other insects, the following enhancements would be useful.

- Look into Bio-Sym program from Jacques Ranier of Canada. According to Kurt Gottschalk this program will allow the separation of the degree-day computation and the use of multiple weather station data points.
- Add the calculation of phenology without elevation (assume flat surface at specified elevation).



# Findings and recommendations

The findings and recommendations in this section do not attempt to answer questions that are properly the role of Forest Health Protection management. Its compilers hope this report provides the information needed to reach the decisions and provide the answers required for the future of the GypsES project. The following subsections include:

- Recommendations to the GypsES development team.
- Observations for Forest Health Protection management.
- Questions for Forest Health Protection management.
- Closing comments by the review team.

The GypsES project started in 1988 as an idea and exploratory effort. More formal software development began when these early efforts resulted in a prototype that showed strong promise as a useful tool for gypsy moth suppression and eradication projects. In the early years, there was no rigorous effort to draft a complete life-cycle project plan that laid out the full costs and resources needed to carry the project through the analysis, design, build, and, more importantly, the implementation and maintenance phases.

Moreover, financial sponsorship has been uncertain at several points during the project's life, and available resources were generally tight considering the complexity of this type of software development. The GypsES development team has done a commendable job of shepherding this project through these years of limited and uncertain finances and uncertain support in general. The functionality of the product they produced probably exceeds that of the original vision of GypsES.

## Recommendations to the GypsES development team

These recommendations assume the questions to management posed in a later subsection are answered in such a way as to continue the GypsES project in some manner.

### **1. Reach closure on version 1.0 of GypsES even if that means slowing down development of additional enhancements.**

Discussion: In reality, Version .9 of GypsES, released in September 1995, could have been considered Version 1.0 if appropriate supporting documentation had been available. Upgrades subsequent to Version .9 have included new features which were not part of the original development plan. Reaching closure on Version 1.0 will enhance the ability of the development team to rigorously plan and manage future enhancements and maintenance activities. It will also avoid projecting the image of a protracted, never-ending project.

### **2. Once Version 1.0 is complete, implement a more structured approach to managing future version releases.**

Discussion: The maintenance task for this project is quite demanding. Fairly frequent distribution of new versions complicates maintenance. This is particularly true when multiple

versions are in use at the same time. No more than two new versions should be distributed in any given year, and the development team should try to keep all users operating with the same version.

**3. Once the development and release of new versions have been regularized, separate new development and enhancements from routine maintenance and support. These should be two separate tasks so that leadership can more clearly assess costs, benefits, and the appropriate roles of Forest Health Protection, the end-users, and other cooperators.**

Discussion: Delivering a turnkey system with all the necessary site-specific datasets can be thought of as a service not unlike the traditional guidance that Forest Health Protection specialists have provided over the years to local gypsy moth program managers. FHP technical assistance has traditionally taken many forms, such as providing an entomologist to help state and county officials implement a gypsy moth suppression program. Similarly, a Forest Health Protection computer specialist can help the same people implement a successful gypsy moth suppression program through the setup and use of GypsES.

Although GypsES is not an expensive project by the standards of decision support software development in general, it appears to be an expensive software development effort compared to the level of funding Forest Health Protection leadership is accustomed to supporting. Currently and for the last two years a substantial part of the GypsES budget has been used not to support GypsES development or even to support bug fixes, but to provide a level of support for end-users that goes far beyond the level typical for software.

**4. When the three tasks outlined above have been achieved, assess and document the costs and benefits for each proposed enhancement. Include an analysis of who the benefactors (end-users) are and who the logical funding contributors should be. Do the same for maintenance and support tasks.**

Discussion: Given the history of general funding uncertainty and the resulting uncertainty on the part of the GypsES development team regarding the level of sponsorship and support they can expect from Forest Health Protection leadership, knowledge of the costs and benefits of each task would be useful. The action recommended here would help to improve communication with all potential sponsors and thereby to sustain consistent sponsorship. Although the development team has no doubt discussed cost/benefit issues, without documentation, communication about these issues with sponsors may not be as effective as it could be.

**5. Annually, or even better, semiannually, formally review technology options for delivering the functionality within GypsES. Document the results of this review. Use these reviews as decision points to determine whether to continue supporting and enhancing the existing system or to reengineer the system for another hardware/software platform.**

Discussion: Computer technology is changing at a breakneck pace. Given the target end-users and related parameters, the GypsES development team made appropriate decisions on how to build and deliver GypsES. However, as a largely custom-coded system with roughly 200,000 lines of code, GypsES requires substantial resources for maintenance and always will. A good part of this maintenance overhead is caused by the dependence of the program code on specific

hardware. Inevitably, as hardware changes, so must the code. In addition, maintenance of GypsES requires specialized skills and would entail a steep learning curve for new maintenance personnel in the event of staff turnover.

If commercial software that can serve as a good platform to deliver GypsES functionality should become available in the future, substituting it for the current platform could substantially reduce GypsES maintenance costs by reducing the data prep time, system configuration time, and the like. In that event, it could be worthwhile to reengineer GypsES to the new software platform. Given the current level of maintenance and user support required, it is not unreasonable to expect that these costs could potentially be cut in half by reengineering GypsES using commercial software. The reviews mentioned in Recommendation 5 should include consultation with other Forest Service software developers.

These reviews should also consider the cost of reengineering options versus the costs of continuing the current situation. Although use of a commercial product to deliver GypsES functionality could substantially increase software costs to the end-user (e.g., PC versions of ArcInfo™ and ArcView™ currently cost about \$2,000 per seat), when one considers the maintenance and support costs of a highly customized system, use of such software might actually be less expensive. In addition, although the current system does not demand high software expenditures, it does require hardware expenditures that might not otherwise be needed. Some existing user-sites already had microcomputers capable of running most commercial software; however, they were forced to buy a specialized microcomputer and related hardware specifically to run GypsES.

**6. Use the above achievements and resulting documents to maintain an ongoing dialog with executive leadership.**

Discussion: Annual, or better, semiannual reviews should be held with participation by executive leadership to review and update plans for the GypsES project. Ongoing management oversight is necessary to avoid surprises for both management and development team. It can also ensure that project sponsorship is consistent and based on better knowledge of the project.

**7. Look for opportunities to cross-train staff and improve system documentation.**

Discussion: Because GypsES is a large, complex, custom-coded system, loss of one key programmer could be devastating to the project and could take as much as a year to recover from. Staff turnover is always disrupting; however good systems documentation and the addition of other staff with strong familiarity with how the product is put together would go a long way toward mitigating this disruption.

**8. Bind the design documents into a notebook to provide one central place for reference by development and maintenance personnel.**

Discussion: These documents are not currently organized and kept in one central location for reference. The logic behind the design of a particular function may not be apparent to new staff, or even to existing staff at a later date. Readily available documentation may help staff understand the logic behind design choices and avoid duplication of effort.

**9. Now that a stable operational version of GypsES is available, make a revised User's Manual a high priority.**

Discussion: This effort should be part of reaching closure on version 1.0. The number of end-users of GypsES appears to be growing rapidly; without a good User's Manual, the development team may be overwhelmed with calls for support. This issue was discussed during this review. The development team is well aware of the issue and has already given priority to this task, as noted in the Software Documentation section of this report.

**10. Include more rigorous in-line coding documentation in future code development and enhancement of existing code.**

Discussion: Given the lean staff, in-line code documentation is actually better than it is on many similar projects. Adding documentation to source code is difficult and time consuming. However, the additional documentation should be added when working on specific program modules in the future for maintenance or new development purposes. The payoff for making this effort is huge if there is staff turnover.

**11. Prepare and/or organize documentation on system and data preparation tasks.**

Discussion: The development team should organize some documentation on the steps and issues involved in preparing a system and on the technical design of GypsES. Although this documentation is not needed by a user site, turnover on the development team could result in a loss of knowledge needed to perform these tasks. In addition, without such documentation, it would be difficult to transfer these tasks to an outside group.

## **Observations for Forest Health Protection management**

During the two-day August meeting in Morgantown between the Enterprise Team review team and the GypsES development team, discussions yielded concerns that have been expressed by many other software development groups in the Forest Service. Probably the most specific concerns of the GypsES team were related to the level of sponsorship to be expected from Forest Health Protection leadership and the consistency of this sponsorship over time.

None of the current GypsES development team staff were original champions of this project. All were asked to serve on this project by Forest Health Protection leadership. Given that these staff were originally directed into this project by leadership, they have at times been perplexed by the uncertainty of Forest Health Protection sponsorship and the consequent feeling that sponsorship is now the problem of development staff.

At the same time that the review of the GypsES project was in progress, a somewhat similar review was underway to evaluate another Forest Service project known as CSDS (Common Survey Data Structure). The CSDS project began three years ago, is sponsored by multiple regions and staffs, and has a much larger budget than GypsES. The CSDS review was conducted by an outside consulting group. Some of the CSDS findings are relevant to the GypsES project and to Forest Health Protection-sponsored software development in general, since many of the themes echoed in the CSDS report also surfaced during the review of GypsES.

Some of the CSDS findings touch on issues related to all major software development projects, including GypsES. Selected quotations from that report are:

“No comprehensive project management plan . . . was developed and agreed to by executive leadership.”

“Executive Leadership does not understand its role, nor the importance of consistent senior level involvement. . . .”

“[Executive leadership not understanding its role] manifests itself in a failure to be involved [in the project] beyond project sponsorship and funding.”

“The fact that the task order initiating this assessment posed the elementary question of ‘what role should [the software] fulfill’, is a clear indication that serious deficiencies exist with the Forest Service strategic process for information management. This question should have been asked, and answered, at the outset of the . . . project. The project sponsors should have been more involved in defining project goals, objectives, and deliverables.”

“The . . . project accomplished much with little or no guidance [from executive leadership] in many areas. It is a project operating ‘off-line’, with little official visibility, lacking in management attention, without a true life cycle plan, adequate full time project staff or funding.”

“The . . . project has operated as a ‘virtual’ project almost from its inception. An informal decision to ‘kick-in’ an arbitrary amount of funds with no clear definition of tangible goals (as expressed in terms of milestones and deliverables), no analysis of the type and level of resources (people and funding) necessary to accomplish the job, has led to the current situation:” [One of the situations cited was] “uncertainty as to the length of funding, availability of new funding, resources tapped largely from volunteers who have other and mostly higher priorities.”

“The Office of Management and Budget (Circular No. A-11, September 14, 1995), identified three shared, critical organizational attributes for successful IT investments; senior management attention, overall mission focus, and a comprehensive approach to IT investment.”

A software project which can be described by the above quotations is likely to find it difficult to schedule tasks and estimate needed funds. Since there is no master plan, it is hard to plan for and meet target dates. Because funding is uncertain and variable, the project may never come to closure. As the CSDS report implies, master plans are not rough estimates of what it will take to develop something; they include detailed goals, schedules, and costs that relate to development AND to long-term maintenance and support. Without a master plan, funding levels are usually somewhat arbitrary. Whether the end product, if one is ever produced, actually meets an organizational need is mostly a matter of luck. As the CSDS report notes, master plans must be developed with active participation and buy-in by senior management.

# Questions to FHP management

Clear answers to the questions listed below should help set the stage for directing future development and support of GypsES.

1. GypsES is a highly customized system. It is unlikely that end-users can or will continue to use GypsES unless supported by some group in a manner similar to that described in this report. Maintenance and support costs are relatively high and will grow as the user-base expands. Should new development continue for this system? Should the system be maintained as is (i.e., with no major enhancements) until it can be reengineered using other commercial software with hopes of reducing maintenance/support costs? Or should the effort be abandoned altogether?
  - a. More specifically, are the benefits of GypsES described in this document worth the current and future costs of sustaining the project given any future development, maintenance, and support options chosen?
  - b. If the answer to question “a” is “no”, how should the GypsES team proceed to close out this project? Walking away from existing users may present a public relations “black-eye”. Expanding the user-base as more systems are delivered and then walking away from these users at some later date as maintenance costs grow will be even more painful.
  - c. If the answer to “a” is “yes”, what level of support in terms of staff time, funding, and management involvement will Forest Health Protection commit to? And for what activities?
  - d. Is the commitment described above sufficient to sustain the project? If not, how can the project be sustained (see next item)? Are your expectations for the project realistic?
2. Given that required funding to sustain this project is not likely to decrease in the near future, where should this funding come from? Whose responsibility is it to secure these funds from the various partners/end-users as well as from Forest Health Protection itself?
  - a. Specifically, what, if any, implementation/maintenance components should the end-user be expected to pay for versus Forest Health Protection covering these costs?
  - b. Specifically, what, if any, new development/enhancements should the end-user be expected to pay for versus FHP covering these costs?
  - c. Specifically, should end-users like APHIS that are contributing some funds be expected to pay for not just their desired enhancements but also for some of the general maintenance and support costs?
3. Should software maintenance and implementation costs be considered a service to end-users just as technical assistance is a service to end-users (i.e., what is the difference between improving Gypsy Moth suppression and eradication activities through funding a FHP specialist’s time to work with people in the field versus funding the maintenance and support of GypsES which assists people in the field in doing the same things with less direct assistance)?
4. Are the current organizational structure and staff responsibilities for GypsES acceptable or should this be adjusted? Should the Enterprise Team have some role in this, and if so, and what should that role be?

5. Beyond funding support, what role will FHP management assume on this project in the future?

In the context of the above questions, efficient direction of this project demands that FHP leadership first address the initial question of whether they will support continuance of this project in light of the described costs and benefits documented here. If leadership determines on some level of continuation the next step is to move quickly to prepare a comprehensive project management plan.

The comprehensive project management plan should address funding issues, organizational structures/responsibilities, timelines, deliverables, and maintenance/support as well as more general goals and objectives. This plan will be of value only if FHP leadership both actively engages in the process of constructing it, and supports the final product.

## Closing comments by Enterprise Team review team

Development and delivery of complex, integrated decision support systems such as GypsES almost always cost much more than more single focused (in terms of technology and components) software such as a simple database application. This should be recognized up front before a project is initiated. On the other hand, the payoff for developing an integrated support system in terms of value to end-users and the organization can be huge. Success on a project like GypsES requires years of dedication and “staying power”.

After eight years, the GypsES development team is on the verge of finalizing a version 1.0 product that exceeds the original vision for the software, and they deserve to be commended. This accomplishment has not been easy. Lean resources and uncertain funding over the years presented a tremendous challenge for the development team. Reaping the benefits of this effort will require continued commitment to maintaining and supporting the product’s use into the future. Although there are choices on how to manage and support this project in the future, all choices have a cost.

The review team thanks all members of the GypsES development team for their openness, candor, and assistance in preparing this report. Digging out the details for a report like this can be difficult, but the development team’s willingness to freely discuss issues and to supply numerous supporting documents greatly facilitated the process.



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# Acronym list and glossary

615 System - the USDA Forest Service's recently implemented UNIX-based corporate hardware and software platform

AGNAV - a navigational system

AIX - IBM's version of UNIX

ANSI - American National Standards Institute

APHIS - Animal and Plant Health Inspection Service

API - Application Programmer Interface

ARC/INFO™ - a commercial GIS product

ARC/View™ - a commercial, user-friendly spatial analysis tool used to view or analyze ARC/INFO™ format files

ASCII - American Standard Code for Information Exchange

Athena™ - a commercial program for producing screen devices

AUX - a UNIX system for the Macintosh

CD-ROM - Compact Disk-Read-only Memory

CERL - U.S. Army Construction Engineers Research Laboratory

CISC - Continuous Inventory of Stand Conditions data base (a Southern Region data base)

Codebase™ - a commercial program for writing code to create and access dBase files

CSDS - Common Survey Data Structure

DAT - Digital audio tape

dBase™ - a commercial, PC-based database product

.dbf - the dBase™ database format

DEM - Digital Elevation Model

DGPS - Differential Global Positioning System

DLG - Digital Line Graph

.dxf - an AutoCAD™ file extension

ESRI - Environmental Science Research Institute, Inc.

FHP - Forest Health Protection, part of the USDA Forest Service, State and Private Forestry

FHTET - Forest Health Technology Enterprise Team, part of Forest Health Protection

FSCBG - Forest Service Cramer-Barry-Grim Spray Deposit and Drift Model

GB - Gigabyte

GIS - Geographic Information System

GMPHEN - Gypsy Moth Phenology Model

GMR&D - Gypsy Moth Research and Development

GPS - Global Positioning System

GRASS - Geographic Resource Analysis Support System - a public domain GIS developed by CERL

GUI - Graphical User Interface - a "point-and-click" or Windows-based user interface to software applications

GypSES - Gypsy Moth Expert System. a PC-based, decision-support software system used to support gypsy moth suppression and eradication efforts

I/O - input-output

IS&T - Information Systems and Technology - a staff of the USDA Forest Service

MB - megabyte

Mosaic™ - a commercial software product for browsing the World Wide Web

Motif™ - a commercial software product for managing windows on UNIX

O/S - Operating System

Oracle™ - a commercial data base product

quad, quad sheet - USGS topographical map quadrangle, electronic version of such a map quadrangle, or the area on the ground covered by such a map quadrangle

raster file - spatially referenced data organized in a grid of columns and rows

SATLOC - a navigational system

SCCS - Source Code Control System

SCSI - Small Computer Systems Interface

SPOT - Systeme Probatoire d'Observation de la Terre - a system of French satellites which produce images of the earth from space

SVR4 - a version of UNIX (System 5, Release 4)

TDP - Technology Development Project

TIFF - Tagged Image File Format - a graphic image format

UTM - Universal Transverse Mercator, a coordinating system used by GIS

UNIX - a computer operating system that exists as many versions as produced by various companies

Unixware™ - a UNIX operating system produced by Novell, now owned by SCO

**USGS - U.S. Geographical Survey**

**VDACS - Virginia Department of Agricultural and Consumer Services**

**vector file** - spatially referenced data that represents physical forms such as points, lines, and polygons.

**widget** - a control such as a window or scrollbar in a GUI

**Windows NT** - the 32-bit version of Microsoft Windows.

**X-server** - software that controls display and input devices for X-windows system

**X-toolkit** - software library used to implement the user interface features for X-windows



# **Appendix A: GypsES status evaluation guide**



# GypsES status evaluation guide

Outline with questions to Guide the Evaluation

First Draft: 6/14/96

## A. Introduction/overview:

What is GypsES?

What is the history of this project?

What are the major reasons for this review?

## B. GypsES functions:

What are the key functions of GypsES? List them and briefly describe each.

## C. Customer analysis:

### 1. Current actual users:

List them.

Do they represent private, county, state, federal non FS, or federal FS entities?

How long have they each been using product?

How long are they expected to use the product and under what circumstances would they stop using it?

How valuable is the product to them? Would they be willing to pay for support, maintenance, and/or enhancements? If so, how much. If not, why not?

Was and is their use of the product dependant on enticements such as free equipment, free data, free commercial software, free support, free training, etc.? If so, what are these expectations?

What investments have current users made in support of this product?

Did they buy special equipment, did they hire new people, did they contribute to development costs, did they provide staff time to write manuals or attend design meetings, etc.?

For each end user, which product functions do they use/value the most, which do they use the least? Summarize across all users to rank value of functions

### 2. Potential future users:

Who are they? Name, type of entity

Why would they want to use the product?

Why are they not now using the product?

If they start using the product, how long can they be expected to use it?

How many user sites may be active a year from now, 2 years from now, 5 years from now?

Would they be willing to pay for support, maintenance, and/or enhancements? If so, how much. If not, why not?

Is their acceptance and use of the product dependant on enticements such as free equipment, free data, free commercial software, free support, free training, etc.? If so, what are these expectations?

## D. Forest Health Protection benefits

To what degree does this product support the mission of Forest Health Protection?

How would achieving the mission and goals of FHP be affected if this software were not available? Based on this degree of mission support, comment on whether it is justifiable for FHP to fully fund development/maintenance/support of this product, to fund a portion of this cost, or not to fund any of it.

In what areas of the United States is this product most likely to be used in the next 5 years

## E. Design issues (How is this thing put together)

### 1. Software

List Commercial/Public Domain Off-the-shelf software used to build product (e.g., GRASS, dBase).

Why were the above software products chosen?

List languages used to build product (e.g., C, C++, X)

Why were the above languages chosen?

What other libraries in addition to the above languages were used?

List other software products used such as GUI toolkits, software testing products, code management products, CASE Tools, etc.

Why were the above products used or NOT used?

In hindsight, did the above software products and languages used to build the system resolve the issues that led to their selection in the first place?

What is the estimated cost to the end-user to purchase needed software in order to run this product?

## **2. Data structures**

What files structures are used by the system (e.g., flat files, dBase format, .TIFF, structures to represent spatial data)

Why were these file structure chosen versus other options?

## **3. Product composition**

Describe what system functions are supported by the each of the software products/languages listed in the section E1.

Does custom code perform any functions which a commercial product such as ARC/View can perform? If so, why was custom code chosen over use of an existing commercial product?

How many lines of code are in the product?

Of the total lines of code, break down this count by each language used.

Describe what each data structure listed in section E2 is used for.

How much disk space is required by the code? How much disk space is required to store the typical amount of input data used? How much disk space is required to store the typical output products? How much disk space is required to store intermediate and temporary files?

## **4. Hardware/operating system**

What hardware system does this product currently run on?

Does the system require any brand specific hardware (i.e., if it runs on a PC, can any brand PC be used)? If so, why?

What is the minimum hardware configuration in terms of RAM, disk space, monitor, and other components?

Does the system require specific hardware components such as certain printers, BIOS, etc.? If so, why?

What operating system is required (note specific version limitations if applicable)?

What are the impediments to porting the system to other operating systems and hardware platforms?

What is the estimated cost of purchasing the suitable hardware platform including the operating system and the usually desired peripherals?

## **5. Skills**

What technical skills were/are needed to build, enhance, and support this system? Describe the staff involved and their skills

## **F. Standards adherence:**

### **1. Life cycle management**

Was Oracle's CASE\*Method used to analyze, design, and build the product?

If not, what method was used to analyze, design, and build the product? Describe.

What documents were produced as a result of analyzing, designing, and building the product (e.g., ERD's, Function Hierarchy, papers, reports)

### **2. 3GL languages**

Do the 3GL languages used to build the product conform to the ANSI language standard?

Do the naming conventions, type definitions, programming style, and software engineering practices conform to standards outlined in manuals by Harbison and Steele? Describe any deviations from these standards.

### **3. User interface**

Is the application consistent with the OSF/Motif user interface in terms of the look and feel, and in terms of function?

### **4. Operating system, GIS, and database**

Are the data structures normalized and well documented?

What standards do the spatial data and functions follow (e.g., follows a given file format as required by a specific version of GRASS)?

What operating system is the product based on? How did this affect development of the product (e.g., required certain compilers)?

### **5. Forest Service specific standards**

Does the product currently run on the 615 platform?

If yes, are there any limitations? If no, why not?

If ported to 615, will the product utilize existing 615 software products such as various libraries, commercial products, and compilers? Which software products will this product use? What software products will be used which are not already part of 615?

Can the software directly use existing FS data stored on 615 or must this data be transformed into different formats for use by the system?

What are the issues and policy constraints that will come into play if this product is installed on 615 (e.g., doesn't use corporate commercial software such as Oracle or ARC/Info, results in 2 GIS products on 615, results in duplicative data, uses too much disk space)?

Can this product be installed without violating FS policies for 615?

What must be done in order for this product to be accepted by IS&T as a national application (e.g., complete ERD, submit various documents for review, reengineer to be consistent with 615 suite of software)? How long will this acceptance process take?

Does the product meet FS standards in terms of life cycle management, 3GL, user interface, operating system, GIS, database, and documentation? If not, which standards are not met and how will this affect attempts to install the product on 615?

## G. Software documentation

### 1. Consider the following documents:

Requirements specifications

Design specifications

Testing specifications

User's manual

Installation manual

Operational manual

Systems manual

Do the above documents exist for this product?

Who was the intended audience for these documents?

If so, what is the status (e.g., % complete, up-to-date) of these documents?

If so, what is the quality (full featured, plenty of graphics, basic text, quick and dirty) of these documents?

How do these documents compare to similar documents for other prominent software systems?

For non-existent or incomplete documents, are there plans to complete these documents? If so, what is the estimated staff time required to complete each of these documents?

For incomplete or non-existent documents, what is the primary reason they are not complete (e.g., lack of staff or resources, low priority)?

### 2. In-line coding documentation

Is the code well documented internally?

Is the code more or less documented than examples of properly documented code as shown in various reference books or FS manuals?

If more in-line code documentation is needed, are there plans to do this? How much staff time would be required to do this?

### **3. On-line help**

Does this product include an on-line help system?

If not, why not? If yes, assess the quality of the system.

Is the on-line help system up-to-date?

What level of effort is required to keep this up-to-date?

### **4. Tutorials, other learning aids**

Do tutorials for learning the system exist?

Do sample datasets exist?

Do other learning aids such as videos, slide packages exist?

## **H. Testing and error handling**

Does a test plan exist?

If yes, who developed it and when, and how the test plan used?

If no, why not?

How was the software tested?

How were the outputs validated?

What is the capability to handle errors (e.g., is it bug prone, how often does it crash, etc.)?

When the system does crash, what are some of the typical problems or events that cause this to happen?

## **I. Development history in terms of cost**

In terms of dollars, what were the yearly funding levels over the life of the project (including staff salaries, travel, equipment, coop and other money sent to universities, outside contracting/consulting costs)?

On a year to year basis, what percent of the funds went to the following activities:

analysis/design, build/development, implementation/support/maintenance? (For example, in 1992 50% of funds were spent on analysis/design work, 50% spent on build/development work, and 0% spent on implementation/support/maintenance. The figures for 1995 might be 0%, 30%, and 70% respectively)

In terms of FS and related staff, how much staff time per year has been spent over the life of the project?

In FY 1996, who (staff person) has been involved with the project? What is their function and how much time are they expected to spend on the project in FY 1996,

On a year to year basis, what percent of the staff time went to the following activities: analysis/design, build/development, implementation/support/maintenance?

Is the current level of funding and staff resources expected to decline, remain the same, or grow in the next year in order to accomplish goals set by the development team? Two years from now? Five years from now?

## **J. Implementation issues/systems administration issues**

### **1. Installation**

How is installation currently done?

How long does it take to install?

Who does the installation?

What skills are required by a person charged with installing?

What kind of installation scripts are available for the installation?

Does installation require that the target system be configured in a particular way? That is, what should the status of the target system be when the installation begins?

Does the installation change the configuration of the target system?

Does the installation restrict the site in the future in terms of their ability to install other software or use the system for other purposes?

Why is the software installed on hardware at the Morgantown site and then shipped to the user site? That is, why doesn't the installation take place on site? Is this practice expected to continue?

What kind of installation documents or manuals exist?

What have been some of the past problems experienced during installations (i.e., unexpected system configuration, equipment incompatibility, equipment breakdowns, corrupt files)

What are the impediments to installation (i.e., FS or other site policies that restrict what and how software is loaded, unskilled site staff)?

What will it take to install on western US sites?

### **2. Training**

When are users trained?

How are users trained?

Who does the training?

Where is training typically held? In Morgantown? At the user site?

Describe the methods used to train.

Are users typically trained such that when the software is installed, they are ready to go?

How often is training conducted?

How many people from a user site are typically trained? Just 1 person or the whole staff?

How often do end users call the development team for advice on using the software? Does the development team track/document the volume of calls and the type of questions asked?

Is follow-up training needed? Is refresher training needed when the following cycle of use begins?

### **3. Routine system administration**

Who handles this activity at the user sites? Are they skilled at this task?

Who is the contact at Morgantown and how time is spent dealing with routine system administration issues?

What skills are required at Morgantown to provide system administration support.

What have been some past system administration issues that were dealt with on current user sites? How often do these occur? Who resolves them? How long does it take?

How are system upgrades handled (i.e., mail upgrade diskette, site visit by development team)?

What routine system administration tasks are required (i.e., backups, data management tasks, removal of temporary files)?

## **K. Maintenance issues (what things come up day to day, future problems, etc.)**

### **1. End user support**

How much end user support is provided (i.e., staff time)?

How often does each site call for support? Are these calls tracked and documented?

If the system is ported to multiple platforms, how will this affect the level and complexity of end user support?

### **2. Common support issues**

Describe some typical problems/issues that end users request help with?

Have these problems/issues changed over time as the system has matured?

### **3. Version control/upgrades**

Is version control software used?

How is version control handled?

Do all sites currently have the exact same flavor of the system?

How often have there been upgrades in the past 2 years?

How are upgrades implemented?

Describe some of the bugs, enhancements, and other reasons addressed in the past several upgrades

Are logs or documents maintained which track bugs, and enhancement requests?

### **4. Effects of changing technologies**

What is the impact of changing hardware and software components that make up the system? For example, a new version of UNIX or GRASS, a new printer or plotter

What will the impact be on GypsES if support for GRASS is dropped by the Federal Government?

### **5. Enhancements**

Do users drive the development process in terms of identifying enhancements or is development driven by a master plan (requirements documentation)?

How are requests for enhancements prioritized?

Describe some of the past enhancements requested by users and describe how much effort it took to implement those that were implemented.

Have any of these enhancements been critical to a specific site such that they would not use the software without the implementation of the enhancement?

## **L. Future plans as recommended by development team**

Desired activities (new implementation, new enhancements, completion of unfinished items, etc.).

Justification for these activities (why do it, benefits, etc.).

Costs for each of the above activities in terms of both cost and staff time.

Staff skills needed to achieve these goals.

## **H. Summary of issues**

**1. Technical issues**

**2. Cost/Benefit issues**

# **Appendix B: User information**



# User information

The following user descriptions are arranged in alphabetical order by user agency name for ease of reference. See Table 2 on page 16 for a summary of this information (Information in Table 2 is organized chronologically).

## **Albemarle County, VA**

Organization: Albemarle County, VA

User Name & Title: Steven Meeks, Gypsy Moth Program Manager

Phone #: 804-984-0727

Address: Albermarle County, 401 McIntire Road, Charlottesville, Va 22902

Unit Leader & Title:

When was system delivered: September 1996

Who bought the system: Albemarle County, VA

What data was delivered on the system: DLG, Topographic maps, SPOT

Who bought the data: VDACS (Virginia Department of Agricultural and Consumer Services)

What product functions do they use the most: new user

Benefits of them using the system (qualitative, anecdotal or \$): Easy access to GIS.

## **Arkansas Plant Board (Arkansas Department of Agriculture)**

Organization: Arkansas Plant Board (Arkansas Department of Agriculture)

User Name & Title: David Blackburn, Asst. Director Plant Industries

Phone #: (501) 225-1598

Address: 1 Natural Resources Drive, Little Rock, AR

Unit Leader & Title: Don Alexander, Director Arkansas State Plant Board

When was system delivered: 1995 (sort of). Due to state regulations ASPB had to go with a competitive bid and purchased a system which did not meet GypsES specification.

GypsES group worked with the low bidder to correct the problems but the sub-par components would not work with Unix-OS. The State has purchased another Gateway P5-166 system which is being set-up to run GypsES. Currently GypsES data is collected on the Pineville Field Office system and will be transferred.

Who bought the system: Arkansas State Plant Board

What data was delivered on the system: Topo Maps, DLG files, DEM data

Who bought the data: Arkansas State Plant Board and University of AR.

What product functions do they use the most: Survey (Eradication), Block design, DGPS import and export.

Benefits of them using the system (qualitative, anecdotal or \$): Provided the Arkansas Dept. of Agriculture with access to GPS.

Comments:

## **City of Alexandria County, VA**

Organization: City of Alexandria County, VA

User Name & Title: Jerry Dieruf, Gypsy Moth Coordinator

Phone #: 703-838-4999

Address: City of Alexandria, 1108 Jefferson St., Alexandria, VA 22314

Unit Leader & Title:

When was system delivered: September 1996

Who bought the system: City of Alexandria County, VA

What data was delivered on the system: topographic maps, DLG, SPOT

Who bought the data: VDACS

What product functions do they use the most: new user

Benefits of them using the system (qualitative, anecdotal or \$):

## **Fauquier County, VA**

Organization: Fauquier County, VA

User Name & Title: Jack Dunlop, Gypsy Moth Program Coordinator

Phone #: 703 347-8734

Address: Fauquier County, 24 Pelham Street, Warrenton, VA 22186

Unit Leader & Title:

When was system delivered: 1995 (April)

Who bought the system: Fauquier County

What data was delivered on the system: topographic maps, SPOT, and DLG data

Who bought the data: VDACS

What product functions do they use the most: EM survey and defoliation prediction; Spray  
block creation with export to DGPS, import of flight lines

Benefits of them using the system (qualitative, anecdotal or \$):

## **Forest Health Protection, Asheville Field Office**

Organization: Forest Health Protection, Asheville Field Office

User Name & Title: John Ghent

Phone #: 704-257-4328

Address: P.O.Box 2680, Asheville, NC 28802

Unit Leader & Title: Robert Anderson, Field Representative

When was system delivered: 1993 June

Who bought the system: FHP

What data was delivered on the system: DLG, DEM

Who bought the data: GypsES development

What product functions do they use the most: Survey (Suppression and Eradication), Map Edit  
for treatment block design, Treatment (FSCBG prediction, DGPS import and export), and  
graphic output for report writing.

Benefits of them using the system (qualitative, anecdotal or \$): GypsES is the only portable  
system available today that can interface with the newest DGPS technology in the field. It  
has been in use for the last three years operationally. In 1996, states that used GypsES to

interface with navigation systems had no problems. All other states (PA, MD, and WV) had difficulties with navigation systems. (Although these states are not users, the GypsES support was able to help them correct their problems.)

Comments: John is a member of the GypsES development group and is a power user of the system.

### **Forest Health Protection, George Washington/Jefferson NF**

Organization: Forest Health Protection, George Washington/Jefferson NF

User Name & Title: Dee Dee Sellers, Entomologist

Phone #: 540-564-8345

Address:

Unit Leader & Title: Robert Anderson, Field Representative

When was system delivered: 1995 September

Who bought the system: Forest Health Protection, Asheville

What data was delivered on the system: DLG, Topo images

Who bought the data: FHP

What product functions do they use the most: Survey (suppression) and defoliation prediction,  
DGPS import and export.

Benefits of them using the system (qualitative, anecdotal or \$):

Comments: Have had only limited use of the system this year.

### **Forest Health Protection, Morgantown, WV**

Organization: Forest Health Protection, Morgantown, WV

User Name & Title: Amy Onken and Karen Felton, entomologists

Phone #: (304) 285-1541

Address: 180 Canfield Street, Morgantown, West Virginia, Morgantown, WV 26505

Unit Leader & Title: Pete Rush, Field Representative

When was system delivered: September, 1995

Who bought the system: GypsES

What data was delivered on the system: topographic maps

Who bought the data: GypsES

What product functions do they use the most: spray block mapping

Benefits of them using the system (qualitative, anecdotal or \$): Links to GPS have helped in suppression project operations.

Comments: They use it to support their cooperators.

### **Forest Health Protection, Pineville, LA**

Organization: Forest Health Protection, Pineville, LA

User Name & Title: Bobbe Fitzgibbon

Phone #: 318-473-7295

Address: 2500 Shreveport Hwy, Pineville, LA 71360

Unit Leader & Title: Dave Drumond, Field Representative

When was system delivered: 1994 April

Who bought the system: Forest Health Protection, Pineville, LA

What data was delivered on the system: DLG, DEM, Topo Maps

Who bought the data: Pineville and Univ. Ark.

What product functions do they use the most: Survey, Map Edit, and DGPS import and export,  
graphic output of topo images with trap locations.

Benefits of them using the system (qualitative, anecdotal or \$): Helps in providing technical  
support to cooperators.

Comments: This early system was used during the 1994 Arkansas eradication project to interface  
with an early version of aircraft GPS. GypsES was used to provide navigation coordinates  
to the aircraft. This project sparked the development of the GypsES-DGPS interface and  
close working relationships with the two primary suppliers of DGPS equipment (SATLOC  
and AGNAV).

## **Indiana Department of Natural Resources**

Organization: Indiana Department of Natural Resources

User Name & Title: Clarence Dunbar, Gypsy Moth Program Assistant

Phone #: (812) 358-3621

Address: Dept. of Natural Resources, 402 W. Washington St. Rm 296, Indianapolis, IN 46204

Unit Leader & Title: Phil Marshall, Entomologist

When was system delivered: 1996 October

Who bought the system: GypsES development group

What data was delivered on the system: topographic maps, DLG

Who bought the data: GypsES

What product functions do they use the most: new user, but will be using pheromone trap survey  
functions.

Benefits of them using the system (qualitative, anecdotal or \$): cost savings in the preparation of  
pheromone trap survey maps which has been done manually.

Comments: Indiana will acquire GypsES in October of 1996.

## **Nelson County, VA**

Organization: Nelson County, VA

User Name & Title: Susan Rorrer, Gypsy Moth Coordinator

Phone #: 804 263-8151

Address: Nelson County, P.O. Box 336 Lovingston, Va. 22949

Unit Leader & Title:

When was system delivered: September 1996

Who bought the system: Nelson County, VA

What data was delivered on the system: topographic maps, DLG, SPOT

Who bought the data: VDACS

What product functions do they use the most: new user

Benefits of them using the system: (qualitative, anecdotal or \$)

## **Ohio Department of Agriculture**

Organization: Ohio Department of Agriculture

User Name & Title: Alan Baumgard, Gypsy Moth Program Director

Phone #: (614) 866-6361

Address: Ohio Dept. of Agriculture, Division of Plant Industry, 8995 East Main St.

Reynoldsburg, Ohio 43068

Unit Leader & Title: David Madison, Specialist in Charge

When was system delivered: 1996 May

Who bought the system: Ohio Department of Agriculture

What data was delivered on the system: topographic maps

Who bought the data: Ohio Department of Agriculture

What product functions do they use the most: mapping treatment areas and defoliation, defoliation prediction, connections to DGPS.

Benefits of them using the system( qualitative, anecdotal or \$): cost of marking spray block boundaries has been greatly reduced. The number of personnel needed to put an operational project together has been reduced because GypsES automates tasks including pheromone trap grid layout, and data entry.

Comments: 1996 was the first year Ohio used a GPS contractor. Without GypsES Ohio would not have been able to use GPS in treatment block layout because the State Department of Agriculture did not have access to a GIS system.

## **Orange County, VA**

Organization: Orange County, VA

User Name & Title: Bert Amidon, Gypsy Moth Coordinator

Phone #: 703-672-1361

Address: Orange County, P.O. Box 30 Orange County, Va. 22960

Unit Leader & Title:

When was system delivered: September 1996

Who bought the system: Orange County, VA

What data was delivered on the system: topographic maps, SPOT imagry, DLG

Who bought the data: VDACS

What product functions do they use the most: new user

Benefits of them using the system (qualitative, anecdotal or \$):

## **National Park Service, Capital Region**

Organization: National Park Service, Capital Region

User Name & Title: Jill Swearigen

Phone #: 202 342-1443

Address:

Unit Leader & Title:

When was system delivered: 1995 September

Who bought the system: National Park Service, Capital Region

What data was delivered on the system: DLG

Who bought the data: Internet and historic GIS data from FHP Asheville.

What product functions do they use the most: Survey (suppression), Map Edit to develop treatment blocks

Benefits of them using the system (qualitative, anecdotal or \$):

Comments:

### **North Carolina Department of Agriculture**

Organization: North Carolina Department of Agriculture

User Name & Title: Dan Wall, State Gypsy Moth Coordinator

Phone #: 919-733-3610

Address: North Carolina Department of Agriculture, P.O. Box 27647, Raleigh, NC 27611

Unit Leader & Title: William Dickerson, Asst. Director of Plant Industry

When was system delivered: 1995 (September)

Who bought the system: GypsES development group via GM coop Suppression

What data was delivered on the system: DLG and Topographic Maps

Who bought the data: GypsES development group bought some of the data; North Carolina Department of Agriculture bought some of the data

What product functions do they use the most: Map Edit to create treatment blocks, Survey (eradication mode) for trap placement, data recording.

Benefits of them using the system (qualitative, anecdotal or \$): Pheromone trap grid layout is automated with GypsES with a considerable savings in labor which would have been used to manually create maps and trap grids.

Comments:

### **Prince William County, VA**

Organization: Prince William County, VA

User Name & Title: Mukesh Patel, Gypsy Moth Control

Phone #: 703-792-4609

Address: Prince William County, 4370 Ridgewood Cntr. Drive, Prince William, Virginia, 22192

Unit Leader & Title: Kim Bowling-Largen

When was system delivered: 1992 June

Who bought the system: GypsES development team (first system, Dell DX4-33), County for second system (1996, Gateway P5-166))

What data was delivered on the system: DLG, topographic maps, SPOT

Who bought the data: GypsES, County GIS group (roads), VDACS

What product functions do they use the most: mapping, Egg mass survey and defoliation prediction, spray block creation, import and export of DGPS info, DBF to produce historic tree record

Benefits of them using the system (qualitative, anecdotal or \$): GIS, data entry and storage

## **Tennessee Department of Forestry**

Organization: Tennessee Department of Forestry

User Name & Title: Bruce Kauffman

Phone #: 615-360-0176

Address: Tennessee Department of Agriculture, P.O. Box 40627, Melrose Station, Nashville, TN  
37204

Unit Leader & Title:

When was system delivered: September 1995

Who bought the system: GypsES development group via coop suppression

What data was delivered on the system: DLG and Topographic maps

Who bought the data: GypsES development group

What product functions do they use the most: Survey (Eradication), Treatment for DGPS activities

Benefits of them using the system (qualitative, anecdotal or \$): In 1994, GypsES was used to help organize and implement an eradication project. Links to GPS were particularly useful.

Comments:

## **Virginia Department of Consumer Services**

Organization: Virginia Department of Consumer Services

User Name & Title: Gary McAnich, Gypsy Moth Programs Coordinator

Phone #: 804-786-3515

Address: Virginia Dept of Agric. & Consumer Services P.O. Box 1163 Richmond, Virginia,  
23209

Unit Leader & Title: Phil Eggborn, Program Manager

When was system delivered: September 1995

Who bought the system: Virginia Department of Consumer Services

What data was delivered on the system: SPOT (Satelite imagery), DLG, Topo maps

Who bought the data: VDACS bought \$10,000 dollars worth of scanned quad maps and satellite SPOT image data.

What product functions do they use the most: Survey and defoliation prediciton, spray block creation, DGPS interface import and export

Benefits of them using the system (qualitative, anecdotal or \$): Allows State to efficiently coordinate county operations.

Comments: Software used in Richmond. They coordinate all Virginia counties. VDACS will use GypsES to run their state-wide gypsy moth program. Have agreed to cost share with counties in VA in setting up GypsES systems. They are planning to purchase another system to run their state Endangered Species Program in VDACS. In 1996, the state purchased satellite imagery to be used as GypsES backdrop for use in treatment block digitizing.

## **Wayne National Forest**

Organization: Wayne National Forest

User Name & Title: Phil Perry, Silviculturist

Phone #: (614) 592-6644

Address: Wayne National Forest, 219 Columbus Road, Athens, Ohio

Unit Leader & Title: Eurial Turner, Supervisor

When was system delivered: no system was delivered. This is a demonstration project for the Forest.

Who bought the system:

What data was delivered on the system:

Who bought the data:

What product functions do they use the most: This demonstration involved hazard rating and using the integrated stand damage model to forecast tree mortality.

Benefits of them using the system (qualitative, anecdotal or \$): Using the integrated hazard rating and stand damage model allowed the Forest to enter stand data and readily develop an environmental analysis.

Comments: Being used by Forest Health Protection, Morgantown for the Wayne National Forest.

# **Appendix C: GypsES: A decision support system for gypsy moth management**



# GypsES: A DECISION SUPPORT SYSTEM FOR GYPSY MOTH MANAGEMENT<sup>1</sup>

Kurt W. Gottschalk, Susan J. Thomas, Daniel B. Twardus, John H. Ghent,  
J. J. Colbert, and Milton E. Teske<sup>2</sup>

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<sup>1</sup>Paper presented in workshop on "Decision Support Systems for Forest Pest Management" at the Ent. Soc. Can./Ent. Soc. B.C. Ann. Meeting, Oct 14-19, 1995 in Victoria, B.C.

<sup>2</sup>Gottschalk, Thomas, and Colbert are with USDA Forest Service, Northeastern Forest Experiment Station, 180 Canfield St., Morgantown, WV 26505. Twardus is with USDA Forest Service, Northeastern Area State and Private Forestry, 180 Canfield St., Morgantown, WV 26505. Ghent is with USDA Forest Service, Region 8 State and Private Forestry, P. O. Box 2680, Asheville, NC 28802. Teske is with Continuum Dynamics, Inc., P.O. Box 3073, Princeton, NJ 08543.

## ABSTRACT

GypsES is a decision support system for gypsy moth (*Lymantria dispar* L.) management being jointly developed by the USDA Forest Service, Northeastern Forest Experiment Station and State & Private Forestry represented by the Northeastern Area, Region 8, and Washington Office Forest Health Technology Enterprise Team - Davis. GypsES provides decision support to gypsy moth managers by: 1) identifying areas of concern; 2) recommending areas to monitor; 3) recommending areas to treat using silvicultural alternatives, direct suppression for established populations, or eradication of localized spot infestations; 4) providing treatment support options for modeling losses with and without treatment; 5) uploading and downloading of spray block and spray line information through global positioning system files, and 6) spray deposition modeling. The system is based on GRASS, a public domain set of geographic information system routines. It has been extended to handle all geographic data, a spatially referenced database, and a full-featured map creation and edit facility using topographic backgrounds. The system was designed and created with a user-friendly interface programmed in C under Unix X-windows/Motif<sup>3</sup>. Also, rule-based logic and independent models are integrated to support users' management decisions. The system can produce reports, create maps, and export graphics files for use in other programs. The basic objectives of GypsES are to model the sequence of evaluations necessary for gypsy moth management decisions and to provide managers with a gypsy moth problem with useful tools to make their work more efficient and enable better decisions.

## INTRODUCTION

GypsES is a computer software package developed for forest pest managers who conduct gypsy moth (*Lymantria dispar* L.) management projects. Developed as a decision support system, GypsES provides pest managers with a toolbox of computer-based assistance. Options include: 1) a geographic information system (GIS) framework enabling the creation of map sets, map analysis, and on-screen digitizing with topographic map backdrops; 2) the use of models to predict defoliation, hazard, risk, tree mortality, phenology, biological dose response, spray deposit and spray drift; 3) a pheromone trap survey assistance package for eradication projects; and 4) an egg mass sample system design and data management module.

GypsES has several components or modules designed to assist in particular phases of gypsy moth management. A Forest component uses forest data to calculate forest susceptibility. Susceptibility is overlaid with gypsy moth population data to create hazard. Hazard is overlaid with management values to create risk.

The Treatment component of the system can be configured either to deal with suppression in established population areas or eradication of localized spot infestations. An Eradication component assists in establishing pheromone trap grids at varying levels of intensity. A Suppression component assists in spray area delineation, predicting potential forest damage within proposed spray areas, predicting spray deposit and drift, and incorporating actual flight lines obtained from geo-positional navigation systems.

GIS functions within GypsES extend a public domain GIS software package, GRASS (US Army Corps of Engineers 1991, Shapiro *et al.* 1992), which has been tailored to fit the needs of pest management operations. A user-friendly interface has been developed for GIS functions, which include on-screen digitizing, map editing, overlays, and import/export procedures. Mapping within GypsES may be done with 1:24,000 scale georeferenced USGS 7½' quad topographic map back-drops. This allows users to actually "see" where they are when creating or displaying

<sup>3</sup>The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service to the exclusion of others that may be suitable.

treatment areas.

The integration of knowledge into a toolbox-type framework is one of the key features of GypsES. For example, within GypsES, a user can use: 1) susceptibility research to determine the likelihood of gypsy moth defoliation; 2) population dynamics research to determine levels of defoliation, and insect development rates; 3) impact research to predict tree mortality; and 4) insecticide deposition research to predict deposit within and outside proposed treatment areas.

## MODELS INTEGRATED INTO GYPSES

A number of models have been integrated into the GypsES toolbox. These include 1) GMPHEN, a gypsy moth phenology mode; 2) a hazard-rating model; 3) defoliation prediction models; 4) Stand-Damage Model; and 5) Forest Service Cramer-Barry-Grim spray deposit and drift model. Additionally, the Gypsy Moth Life System Model is being converted to Unix to be added into Version 2.0 of GypsES. A short description of these models follows.

### GMPHEN - Phenology Model

The gypsy moth phenology model, GMPHEN, was developed from several published papers on various aspects of gypsy moth development relative to temperature, via degree-day accumulations (Sheehan 1992). It was originally developed as part of the Gypsy Moth Life System Model and has been extracted as a stand-alone version. The model uses daily maximum and minimum temperatures to calculate heat accumulation measured in degree-days. The user can use built-in 30-year averages for gross estimates of timing of egg hatch and larval development, or input the actual temperature data up to the current date and then use the model to simulate into the future. After the phenology model is run for data from a specific weather station, the results are displayed across the landscape by using the elevation data from digital elevation models (DEMs) to adjust for differences using an

adiabatic gradient (Schaub *et al.* 1990a). The phenology layers calculated within GypsES can be used for planning many operations, including organizing spray blocks into units of similar phenology, timing spray applications for maximal efficacy, planning pheromone trap placement and pickup, and timing pheromone application for mating disruption.

### Hazard-Rating Model

The hazard-rating model is designed to incorporate all the elements of the forest conditions and management considerations that are necessary as a precursor to any gypsy moth-related activity. These elements include primarily information on the types of trees in the areas of concern so that the system can determine the susceptibility to gypsy moth defoliation. Vulnerability to damage is then calculated based on the stocking, vigor, and prior disturbance history as described by the user (Elmes *et al.* 1993, Twery *et al.* 1993, Bennett 1995). The effects of defoliation and damage on management objectives are then incorporated to produce a hazard rating. This hazard rating can be used to help determine sampling needs. In return, information from the defoliation prediction model is used within the hazard rating model to predict current risk of a gypsy moth infestation significant enough to require management intervention. These terms are further defined in a subsequent section dealing with hazard rating.

### Defoliation Prediction Models

Two defoliation prediction models have been included in GypsES, with the user able to select the model desired. Gansner *et al.* (1985) developed a model based on counts of egg masses per acre. A similar model that uses forest site information in addition to egg mass counts is available (Montgomery 1990). Both models are used to estimate defoliation for either an individual egg mass sample plot or from an egg mass surface generated by GypsES using the egg mass sample plots. The estimated defoliation is used by the hazard-rating model to estimate risk. When managers have management objectives that call for

reducing defoliation, they can use estimated defoliation to determine areas that need suppression treatments.

### Stand-Damage Model

The Stand-Damage Model is a stand-alone model that was developed as part of the Gypsy Moth Life Systems Model (Colbert and Sheehan 1995). It simulates forest growth, mortality, and regeneration, and includes the ability to apply defoliation percentages to trees present in the simulated stand. Gypsy moth outbreak effects on growth and mortality can be compared to simulations of the same stand without defoliation. The model requires that data on tree species and number of stems in each diameter class be input. The model can be run in two modes: interactively or via pre-defined scenarios. When run interactively, the user actually leaves GypsES, runs the Stand-Damage Model independently, and returns automatically to GypsES. Currently, the outputs from interactive runs cannot be used within GypsES without re-entering the results into a database file. Interactive runs also can compare the results of silvicultural treatments that the user can apply to stands. Predicted defoliation from the hazard rating system can be used as input to examine the impacts of gypsy moth on stands.

The pre-defined scenarios will take the stand data present in a database file in GypsES, run the Stand Damage Model, and return tables and graphic output back to GypsES. These scenarios are for no defoliation (baseline), light defoliation, and heavy defoliation, and all run for two 5-year identical defoliation sequences to provide a decade length projection. Outputs from these scenarios include stem counts, board foot volume, sawlog volume, and total merchantable volume for all three scenarios, as well as values for the no defoliation minus the light and the no defoliation minus the heavy defoliation scenarios. These differences provide direct estimates of basal area or volume losses and permit users to estimate discounted total dollar losses when species-specific board-foot values (\$/MBF) are supplied.

### FSCBG Spray Deposit and Drift Model

The Forest Service Cramer-Barry-Grim (FSCBG) spray deposit model, developed by the USDA Forest Service under the direction of John W. Barry, Forest Health Technology Enterprise Team, Davis, California, is used within GypsES as the method to calculate potential deposit within a treatment area, and potential drift to exclusion zones nearby (Teske et al. 1993). A user-friendly interface has been created, within GypsES, providing simple access to FSCBG. GypsES passes FSCBG a spray block with a proposed or an actual flight line and expected or actual weather conditions at the time of spraying. FSCBG then runs a simulation based on these conditions and the aircraft type, nozzles, and other factors producing estimates of the amount of spray material that lands within the block and the amount that drifts outside the block. Contours are returned to GypsES for various droplet densities that occur. These contours are displayed over the spray block boundaries. Enhancements currently under development include calculation of success zones using biological dose-response relationships and fitting actual spray flight lines over predicted flight lines.

### KNOWLEDGE BASES INCORPORATED INTO GYPSES

Knowledge bases developed by teams of experts in the areas of hazard-rating, survey and monitoring, and treatment have been incorporated into the GypsES structure. Short descriptions of these areas are included.

#### Hazard Rating

Hazard rating is important because it allows efficient allocation of financial and other resources to meet challenges from particular dangers to the management goals. Rating of forests with regard to hazard from forest insects has been done extensively for many insects in many forest types (Hedden et al. 1981) and is generally regarded as a useful

management tool. To be useful, however, a great deal of information is needed about the individual forest stand and the pest insect population. In general terms, the necessary stand information includes species composition, stocking level, tree vigor, and stress levels. The population levels of the pest insect also are important in estimating timing of potential damage (risk), but are not necessary to estimate long-term hazard.

Gypsy moth hazard rating includes the determination of where a problem is most likely to occur given certain conditions, and how severe any damage is likely to be. Although gypsy moth may be a problem across very large areas at times, the specific areas of forest where it may be found vary from year to year. Also, individual stands within the same major forest type and in the same geographic area may have very different potential hazards. Under some management objectives, such as high-use recreation areas, damage may be defined differently and include the mere presence of high insect populations rather than any damage to the trees.

Definitions of four terms are necessary to understand the current hazard rating system for gypsy moth. Susceptibility is the term used for the likelihood of defoliation of a given tree or stand when and if the gypsy moth is present. Vulnerability is the probability that damage (e.g. mortality, growth loss, reduced scenic beauty) will result if defoliation occurs. Hazard combines the probability and severity of damage with its effects on management goals for a specific area. Risk incorporates insect population trends to predict the probability that such an event damaging to the management goals will occur in the short term.

Gypsy moth hazard rating is based on information of varying quality. It is well documented that gypsy moth larvae feed on particular host species (Mosher 1915, Montgomery 1991). Susceptibility is a relatively straightforward function of species composition modified by site and stand characteristics (Gansner *et al.* 1987). Vulnerability is a more complicated relationship. The primary complicating factor is the amount of additional stress to which an

individual tree has been subjected. Estimates of individual tree vulnerability to mortality have been compiled for many species in Pennsylvania (Gansner *et al.* 1987, Hicks and Fosbroke 1987) and are still being refined. Stand-level vulnerability to mortality, which is a more useful scale to the forest manager, can be 1) accumulated from individual tree data from sample plots, 2) estimated by applying individual tree probabilities to stand tables, or 3) estimated using a stand-level equation based on plot surveys. The stand-level equation is easier to calculate, but is somewhat more variable because of the information it necessarily omits.

Forests of the Northeast have been classified as to their general susceptibility and vulnerability to gypsy moth. The various types of mixed oak forests are most susceptible because the trees are preferred hosts for gypsy moth. Classification of vulnerability to mortality is more difficult, because it must incorporate stand history, current stand conditions, presence of secondary mortality agents, insect population trends, and predictions of future conditions of the trees. Several attempts have been made to predict mortality of stands, but the equations do not fit other geographic areas or different stand conditions because of the specific characteristics used. After the biological factors influencing the impact of gypsy moth have been estimated, a useful hazard rating system must account for the objectives of the land managers and how the potential disturbance from defoliation will influence those objectives. As with most sociological factors, principles can be framed, but little real information is available. Highly reliable information on the relationship between defoliation levels and insect population levels is also still lacking.

Existing gypsy moth hazard ratings are based primarily on species and condition of individual trees. When such information is available, it is the best source from which to predict hazard to the forest. However, many areas of forest or partially forested land will not have such detailed information but a decision still will be needed on how to deal with the potential threat of gypsy moth.

## Survey and Monitoring

Techniques and methodology for sampling gypsy moth and its associated natural enemies have been developed and in some instances tested and validated. The treatment threshold concept is central not only to sequential sampling but also to integrated pest management in general. Sampling for research purposes varies with the nature of the study and usually is more intensive than techniques used by managers. Managers usually require samples over large areas of variable habitat and are constrained by time and economics. For gypsy moth, egg mass, late instar larvae, male adult, frass, and head capsule sampling can be used but none have proven totally effective for making management decisions. Pheromone traps are a sensitive means of detecting male moths but are limited to detecting and delimiting new infestations. Egg-mass counts are routinely used by managers to decide on the need for suppression tactics. Currently used methods are fixed-area plots (Wilson and Fontaine 1978) and sequential sampling (Kolodny-Hirsch 1986, Fleischer *et al.* 1991) that provide only number of egg masses per acre and have not been a dependable predictor of defoliation (Liebhold *et al.* 1994). Factors such as forest site, foliar biomass, insect population trends, egg mass size, and phenology are important components of predicting defoliation for purposes of initiating management action.

The sampling support component of GypsES provides a user with means to design the layout of sampling grids for pheromone, egg mass, or larval sampling. The user can track the placement of pheromone traps or sampling plots, record sampling data, and use the results to generate density estimate layers within the GIS. The data derived from initial surveys can be used to extend or articulate further sampling programs. The results of sampling programs provide data used along with other information to set up and prioritize management units strategies, including eradication, suppression, or silvicultural alternatives.

Currently, the implementation of truly integrated gypsy moth management programs

is constrained by an inability to forecast outbreaks with adequate accuracy. There is substantial evidence that many areas designated for treatment never would reach damaging densities. Conversely, populations in stands that are rejected for treatment often increase to defoliating levels.

## Treatment - Suppression and Eradication

The survey portion of GypsES includes two modes of operation: suppression and eradication. Suppression mode is used when gypsy moth populations are high enough that defoliation or nuisance is expected to have significant effects on management objectives for the area. Eradication mode is used in spot infestations that are outside the generally infested and transition zones. The objective in these spot infestations is to eradicate the gypsy moth. Both modes include expert knowledge on insecticide treatments, mass trapping, delimitation trapping, and pheromone-based mating disruption (Schaub *et al.* 1990b). FSCBG also contains expert knowledge related to insecticide applications, spray drift, and spray deposit. Treatment effectiveness can be evaluated by comparing pre- and post-treatment values for egg masses, defoliation, pheromone trap catches, and other measures.

## SYSTEM FEATURES

GypsES is an X-Windows/Unix application and runs on computers with a 486 DX2-66 and faster or a Pentium processor, with at least 32 mb of RAM running UnixWare V2.0. Due to the enormous amounts of data used in mapping applications, GypsES requires hard disk storage capabilities in the gigabyte range. Also, it can be modified to run on other types of Unix workstations, but would require a moderate amount of programming dependent upon the operating system. GRASS, a public domain full-featured GIS, was chosen since it is powerful, we could obtain the source code, and we do not have to pay license fees to distribute it (US Army Corps of Engineers 1991, Shapiro *et al.* 1992). All GypsES spatial data formats

are based on the GRASS system. A spatially referenced database was developed that uses standard Xbase (.DBF) database file formats. A graphical user interface (GUI) written in C using X-Windows/Motif provides the structure for the GypsES menu system. All models, rule bases, and GIS functions are accessed through the GUI menu structure and nested windows. Four work windows are used for all operations. The system will print directly or can save output to graphics files that can then be imported into other programs such as word processors, office publishers, and presentation packages. The report generator can create printed output for many of the operations. GypsES is a large, complex program, containing over 250,000 lines of program source code, in addition to some of the models it includes.

## Menu Structure

The main menu contains seven major pull-down menu groups. These groups are: file, edit, windows, forest, survey, treatment, and help menus. Short descriptions of each submenu and some examples of functions available within GypsES follow.

### *File menu*

The File menu provides basic file control functions such as deleting, renaming, copying, setting data links, and importing and exporting files. The user can select the mapset location to work with. This allows a user to have multiple locations, each of a size that is on the order of a county or ranger district. This menu allows the editing of maps and access to many GIS functions such as overlay, combine, reclass, and surface generation.

### *Edit menu*

The Edit menu provides the ability to enter or change data, edit data tables, and create or edit map files, including on-screen digitizing. This section is also where many user defaults can be set, such as management objectives for areas, survey parameters, and units of measure.

### *Windows menu*

This menu allows the user to change how information is displayed on the screen, including choice of map layers, fonts, colors, symbol size and type, and number of simultaneous windows (one or four). Also, it provides view change (zoom in/out) and masking.

### *Forest menu*

The Forest menu allows the user to create hazard layers using GIS layers such as stand boundaries, defoliation, and management objectives. The Stand-Damage Model is accessed from this menu for both interactive and pre-defined scenarios. This menu can be used to identify areas where silviculture and other non-insect-focused activities may be beneficial to National Forests and other forest management organizations, even before arrival of gypsy moth in an area. Conducting hazard-ratings and simulations of mortality following outbreaks via the pre-defined scenarios can identify stands that are the highest priority for silvicultural management. This process will be made even easier in Version 2, when rulebases for silvicultural treatments are added to the system. Also, through this menu, one can provide similar prioritization and help in the planning process for eradication and suppression projects.

### *Survey menu*

The Survey menu has two different modes: suppression and eradication. In suppression mode, it allows editing or viewing of egg mass surveys and their results, generates an egg mass surface using a surface generation routine, and runs the defoliation prediction model to generate a defoliation surface. In eradication mode, it can help the user to create a pheromone trap survey design or detection grid, allow entry of trap data, and view pheromone trap data.

### *Treatment menu*

The Treatment menu has many options. Activities that can be conducted in a pretreatment situation include: 1) generating a risk layer from hazard and predicted defoliation surface; 2) creating, editing, and viewing a spray blocks layer; 3) running the phenology model to create a phenology layer to time treatment at peak second-instar development or time putting out and picking up pheromone traps; 4) uploading the spray block boundaries to the spray planes via digital global positioning system (DGPS) files; and 5) running the FSCBG spray deposit and drift model in a gaming fashion, to determine what weather conditions are appropriate to treat in. Post-treatment activities that can be done include: 1) downloading actual spray lines from the spray planes via DGPS files; 2) displaying actual spray lines over the spray blocks; 3) running FSCBG using actual spray lines and weather conditions to see the deposit and drift contours that occurred; 4) calculating egg mass difference layers and overlaying spray blocks to see how effective the treatment was in reducing egg mass densities; 5) overlaying defoliation and spray blocks to see how effective the treatment was in reducing defoliation; 6) overlaying pheromone trap catches and treatment blocks to determine efficacy of the treatment; and 7) calculating pheromone trap difference layers and overlaying treatment blocks to determine efficacy. The user can develop many reports from the Treatment menu. Information such as total acres in spray blocks, acreage of each kind of treatment, potential cost of the treatments, grouping of spray blocks by phenology, and many more useful pieces of information can be obtained from the system. In the past, doing these kinds of analyses by hand was very time consuming and prone to mistakes.

#### *Help menu*

The Help system contains context-sensitive help for the user. It contains much of the same information as in the reference manual and is always available to the user. In some instances, it contains details not documented elsewhere.

## IMPLEMENTATION

At present, GypsES has a beta test group of 12 users including: 1) Prince William County Virginia; 2) the Arkansas Plant Board; 3) the Virginia Department of Consumer Affairs; 4) the Ohio Department of Agriculture; 5) the Indiana Department of Natural Resources; 6) the North Carolina Department of Agriculture; 7) the Tennessee Division of Forestry; 8) the USDI National Park Service, National Capital Region; and 9) USDA Forest Service State & Private Forestry offices in Morgantown, WV, Asheville, NC, Pineville, LA, and Harrisonburg, VA. All users are actively involved in gypsy moth suppression or eradication projects. As we gain experience with these users, additional sites will be added each year, as new users seek access to the system.

## FUTURE ENHANCEMENTS

While the final touches are being placed on the version 1.0 release, we are actively pursuing additional enhancements to the 2.0 version of GypsES. These include: 1) incorporation of the Gypsy Moth Life System Model; 2) further development of the FSCBG interface and capabilities including a) deposit within exclusion zones, b) optimization/readjustment of flight lines to maximize deposit within blocks, linkage of DGPS actual flight lines to FSCBG, help system, and c) calculation of percent success within blocks using dose-response interactions; 3) addition of economic analyses to the Stand-Damage Model; 4) incorporation of silvicultural guidelines rulebases; 5) development of a revised GMPHEN model; and 6) evaluation of BioSIM (Régnière and Bolstad 1994, Régnière *et al.* 1995, Régnière and Logan 1996, this proceedings) for replacing the current landscape-level temperature input for phenology.

As the reader can see, the GypsES development team has set their goals high - to provide a field application-oriented, user-friendly toolbox to support decisions and to continually improve on that toolbox as new information and techniques become available. Further information about GypsES, computer

system requirements, and availability can be obtained by contacting any of the authors.

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# **Appendix D: An overview of GypsES: The gypsy moth decision support system**



## AN OVERVIEW OF GYPSES THE GYPSY MOTH DECISION SUPPORT SYSTEM

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Written for Presentation at the  
1996 ASAE Annual International Meeting  
Sponsored by ASAE

Phoenix Civic Plaza  
Phoenix, Arizona  
July 14-18, 1996

### Summary:

This paper summarizes GypSES, the vision driving its use for gypsy moth management, and the components that make up this emerging decision support system. This paper provides overview details on its many options, models (gypsy moth phenology, forest hazard-rating, defoliation prediction, forest stand damage, and FSCBG), and knowledge bases (hazard rating, survey and monitoring, and treatment).

### Keywords:

Decision Support, Aerial Spraying, Gypsy Moth, Computer Software

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# AN OVERVIEW OF GYPSES THE GYPSY MOTH DECISION SUPPORT SYSTEM

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## ABSTRACT

For the last five years a focused effort has been undertaken by the USDA Forest Service in the development and refinement of a decision support system for gypsy moth management. This system, called Gypses, contains mapping capabilities, database management, a forest stand damage prediction model, and the USDA Forest Service aerial spray prediction model FSCBG for the prediction of deposit and drift effects from gypsy moth spray projects. Gypses has been used in operational sites in the Northeast during the last twelve months, and it now seems reasonable to summarize the model itself, the vision driving its use, and the components that make up this emerging decision support system. This paper provides these overview details.

## OVERVIEW

Gypses is a decision support system for gypsy moth (*Lymantria dispar* L.) management being jointly developed by the USDA Forest Service, Northeastern Forest Experiment Station and State & Private Forestry represented by the Northeastern Area, Region 8, and Washington Office Forest Health Technology Enterprise Team -- Davis. Gypses provides decision support to gypsy moth managers by: (1) identifying areas of concern; (2) recommending areas to monitor; (3) recommending areas to treat using direct suppression for established populations, or eradication of localized spot infestations; (4) providing treatment support options for modeling losses with and without treatment; (5) uploading and downloading spray block and spray line information through global positioning system files; and (6) spray deposition and drift modeling. The system is based on GRASS, a public domain set of geographic information system routines. It has been extended to handle all geographic data, a spatially referenced database, and a full-featured map creation and edit facility using topographic backgrounds (1:24000 USGS quadrangles). The system was designed and created with a user-friendly interface written in C under Unix™ X-Windows™ Motif™. Rule-based logic and independent models are integrated to support the decision-making process. The system can produce reports, create maps, and export graphics files for use in other programs. The basic objectives of Gypses are to model the sequence of evaluations necessary for gypsy moth management decisions and to provide managers with a gypsy moth problem with useful tools to make their work more efficient, enable better decisions, and improve effectiveness of treatment.

## INTRODUCTION

Gypses is a computer software package developed for forest pest managers who conduct gypsy moth (*Lymantria dispar* L.) management projects. Developed as a decision support system, Gypses provides pest managers with a toolbox of computer-based assistance. Options includes:

- o A geographic information system (GIS) framework enabling the creation of map sets, map analysis, and on-screen digitizing with topographic map backdrops;
- o Geographic positioning system (GPS) files which can be imported and exported;
- o The use of models to predict defoliation, hazard, risk, tree mortality, phenology, biological dose response, and spray deposit and drift;
- o A pheromone trap survey assistance package for eradication projects; and
- o An egg mass sample system design and data management module.

GypsES has several components or modules designed to assist in particular phases of gypsy moth management:

- o A *FOREST* component uses forest data to calculate forest susceptibility. Susceptibility is overlaid with gypsy moth population data to create hazard. Hazard is overlaid with management values to create risk.
- o A *TREATMENT* component can be configured for suppression in established population areas or eradication of localized spot infestations.
- o An *ERADICATION* component assists in establishing pheromone trap grids at varying levels of intensity.
- o A *SPRAY ADVISOR* component assists in spray area delineation, predicting potential forest damage within proposed spray areas, predicting spray deposit and drift, and incorporating actual flight lines obtained from geo-positional navigational systems.

GIS functions within GypsES extend a public domain GIS software package called GRASS (U. S. Army Corps of Engineers 1991; Shapiro et al. 1992), which has been tailored to fit the needs of pest management operations. A user-friendly interface has been developed for GIS functions, including on-screen digitizing, map editing, overlays, and import/export procedures. Mapping within GypsES may be done with 1:24000 scale geo-referenced USGS 7-1/2 ft quad topographic map backdrops. This approach allows users to actually "see" where they are when creating or displaying treatment areas.

The integration of knowledge into a toolbox-type framework is one of the key features of GypsES. For example, within GypsES, a user can use: (1) susceptibility research to determine the likelihood of gypsy moth defoliation; (2) population dynamics research to determine levels of defoliation and insect development rates; (3) impact research to predict tree mortality; and (4) insecticide deposition research to predict deposit within and outside proposed treatment areas.

## MODELS INTEGRATED INTO GYPSES

A number of models have been integrated into the GypsES toolbox. These include: (1) GMPHEN, a gypsy moth phenology model; (2) a forest hazard-rating model; (3) defoliation prediction models; (4) a forest stand damage model; and (5) FSCBG (Forest Service Cramer-Barry-Grim) spray deposit and drift model. Additionally, the Gypsy Moth Life System Model is being converted to UNIX to be added into Version 2.0 of GypsES. A short description of each of these models follows.

## GMPHEN -- A Gypsy Moth Phenology Model

The gypsy moth phenology model GMPHEN was developed from several published papers on various aspects of gypsy moth development relative to temperature, via degree-day accumulations (Sheehan 1992). It was originally developed as part of the Gypsy Moth Life System Model and has been extracted as a stand-alone version for GypsES. The model uses daily minimum and maximum temperatures to calculate heat accumulation measured in degree-days. The user can access built-in 30-year averages for gross estimates of timing of egg hatch and larval development, or input the actual temperature data up to the current date and then use the model to extrapolate into the future. After the phenology model is run for data from a specific weather station, the results are displayed across the landscape by using the elevation data from digital elevation models (DEMs) to adjust for differences using an adiabatic gradient (Schaub, Logan and Ravlin 1990). The phenology layers calculated within GypsES can then be used for planning many operations, including: (1) organizing spray blocks into units of similar phenology; (2) timing spray applications for maximum efficacy; (3) planning pheromone trap placement and pickup; and (4) timing pheromone application for mating disruption.

## Hazard-Rating Model

The hazard-rating model is designed to incorporate all elements of the forest conditions and management considerations necessary as a precursor to any gypsy moth-related activity. These elements primarily include information on the types of trees in the areas of concern, so that the system can determine their susceptibility to gypsy moth defoliation. Vulnerability to damage is calculated based on the stocking, vigor, and prior disturbance history as described by the user (following Elmes, Liebhold and Twery 1993; Twery et al. 1993; and Bennett 1995). The effects of defoliation and damage on management objectives are then incorporated to produce a hazard rating. This rating can be used to help determine sampling needs. In return, information from the defoliation prediction model is used within the hazard-rating model to predict current risk of a gypsy moth infestation significant enough to suggest management intervention.

## Defoliation Prediction Models

Two defoliation prediction models have been included in GypsES, with the user able to select the model desired. Gansner, Herrick and Ticehurst (1985) developed a model based on counts of egg masses per acre. A similar model that uses forest site information in addition to egg mass counts is also available (Montgomery 1990). Both models are used to estimate defoliation for either an individual egg mass sample plot or from an egg mass surface generated by GypsES using the egg mass sample plots. The estimated defoliation is used by the hazard-rating model to estimate risk. When managers have management objectives that call for reducing defoliation, they can use estimated defoliation predictions to determine areas that need suppression treatments.

## Stand Damage Model

The stand damage model is a stand-alone model that was developed as part of the Gypsy Moth Life Systems Model (Colbert and Sheehan 1995). It simulates forest growth, mortality, and regeneration, and includes the ability to apply defoliation percentages to trees present in the simulated stand. Gypsy moth outbreak effects on growth and mortality can be compared to simulations of the same stand without defoliation. The model requires that data on tree species and number of stems in each diameter class be input. The model can be run in two modes: interactively or via pre-defined scenarios. When run interactively, the user actually leaves GypsES, runs the stand damage model independently, and then returns automatically to GypsES after exiting stand damage (currently, the outputs from interactive runs cannot be used within GypsES without first re-entering the results into a database file). Interactive runs can also compare the results of

silvicultural treatments the user can apply to the stands. Predicted defoliation from the hazard rating system can be used as input to examine the impacts of gypsy moth on stands.

The pre-defined scenarios take the stand data present in a database file in GypsES, run the stand damage model, and return tables and graphical output back to GypsES. These scenarios are for no defoliation (baseline), light defoliation, and heavy defoliation, all run for two five-year identical defoliation sequences to provide a decade-length projection. Output from these scenarios include stem counts, board foot volume, saw log volume, and total merchantable volume for all three scenarios, as well as values for the no-defoliation minus the light-defoliation and the no-defoliation minus the heavy-defoliation scenarios. These differences provide direct estimates of basal area or volume losses and permit users to estimate discounted total dollar losses when species-specific board-foot values (\$/MBF) are supplied.

### FSCBG Spray Deposit and Drift Model

The Forest Service Cramer-Barry-Grim (FSCBG) spray deposit model developed by the USDA Forest Service under the direction of John W. Barry, Forest Health Technology Enterprise Team, Davis, CA, is used within GypsES as the method for calculating potential deposit within a treatment area, and potential drift to exclusion zones nearby (Teske et al. 1993). A user-friendly interface has been created within GypsES, providing simple user access to FSCBG. GypsES passes FSCBG a user-selected spray block with a proposed or actual flight line (or lines), and expected or actual weather conditions at the time of spraying. FSCBG then runs a simulation based on these conditions and the aircraft type, nozzles, and other factors, to predict the amount of spray material that lands within the spray block and the amount that drifts outside the spray block. Contours are returned to GypsES for the various droplet densities that occur. These contours are then displayed over the spray block boundaries to estimate the extent of the spray deposition and drift on the selected spray block and the area surrounding it. Enhancements currently under development include calculation of success zones using known gypsy moth biological dose-response relationships, and fitting actual spray flight lines from GPS with predicted flight lines.

## **KNOWLEDGE BASES INCORPORATED INTO GYPSES**

Knowledge bases developed by teams of experts in the areas of hazard rating, survey and monitoring, and treatment have been incorporated into the GypsES program structure. Short descriptions of these knowledge bases follow.

### Hazard Rating

Hazard rating is important because it allows efficient allocation of financial and other resources to meet challenges from particular dangers to the management goals. Rating of forests with regard to hazard from forest insects has been done extensively for many insects in many forest types (see for example Hedden, Abarras and Coster 1981) and is generally regarded as a useful management tool. To be helpful, however, a great deal of information is needed about the individual forest stand and the pest insect population. In general terms, the necessary stand information includes species composition, stocking level, tree vigor, and stress levels. The population levels of the pest insect are also important in estimating timing of potential damage, but are not necessary to estimate long-term hazard.

Gypsy moth hazard rating includes the determination of where a problem is most likely to occur -- given certain conditions -- and how severe any damage is likely to be. Although gypsy moth may be a problem across very large areas at certain times, the specific areas of forest where the gypsy moth is found may vary considerably from year to year. Also, individual stands within

the same major forest type and in the same geographic area may have very different potential hazard levels. Under some management objectives, such as high-use recreation areas, damage may be defined differently and include the mere presence of high insect populations rather than any apparent damage to the trees.

Definitions of four terms are necessary to understand the current hazard rating system for gypsy moth. *Susceptibility* is the term used for the likelihood of defoliation of a given tree or stand when and if the gypsy moth were present. *Vulnerability* is the probability that damage (such as mortality, growth loss, or reduced scenic beauty) will result if defoliation occurs. *Hazard* combines the probability and severity of damage with its effects on management goals for a specific area. *Risk* incorporates insect population trends to predict the probability that such an event damaging to the management goals will occur in the short term.

Gypsy moth hazard rating is based on information of varying quality. It is well documented that gypsy moth larvae feed on particular host species (Mosher 1915; Montgomery 1991). Susceptibility is a straightforward function of species composition modified by site and stand characteristics (Gansner et al. 1987). Vulnerability is a more complicated relationship. The primary complicating factor is the amount of additional stress to which an individual tree has been subjected. Estimates of individual tree vulnerability to mortality have been compiled for many species in Pennsylvania (Gansner et al. 1987; Hicks and Fosbroke 1987) and are still being refined. Stand-level vulnerability to mortality, which is a more useful scale to the forest manager, can be: (1) accumulated from individual tree data from sample plots; (2) estimated by applying individual tree probabilities to stand tables; or (3) estimated using a stand-level equation based on plot surveys. The stand-level survey is easiest to calculate, but is somewhat more variable because of the information it necessarily omits.

Forests in the Northeast have been classified as to their general susceptibility and vulnerability to gypsy moth. The various types of mixed oak forests are most susceptible because the trees are preferred hosts for gypsy moth. Classification of vulnerability to mortality is more difficult, because it must incorporate stand history, current stand conditions, presence of secondary mortality agents, insect population trends, and predictions of future conditions of the trees. Several attempts have been made to predict mortality of stands, but the equations do not fit other geographic areas or different stand conditions because of the specific characteristics used. After the biological factors influencing the impact of gypsy moth have been estimated, a useful hazard rating system must account for the objectives of the land managers and how a potential disturbance from defoliation will influence those objectives. As with most sociological factors, principles can be framed, but little real information is available. Highly reliable information on the relationship between defoliation levels and insect population levels is also still lacking.

Existing gypsy moth hazard ratings are based primarily on species and the condition of individual trees. When such information is available, it is the best source from which to predict hazard to a forest. However, many areas of forest or partially forested land will not have such detailed information, but a decision still will be needed on how to deal with the potential threat of gypsy moth.

#### Survey and Monitoring

Techniques and methodology for sampling gypsy moth and its associated natural enemies have been developed and in some instances tested and validated. The treatment threshold concept is central not only to sequential sampling but also to integrated pest management in general. Sampling for research purposes varies with the nature of the study and is usually more intensive than techniques actually used by forest managers. Managers usually require samples over large areas of variable habitat, and are constrained by time and economics. For gypsy moth, egg mass, late instar larvae, male adult, frass, and head capsule sampling can be used, but none has proven

totally effective for making management decisions. Pheromone traps are a sensitive means of detecting male moths but are limited to detecting and delimiting new infestations. Egg-mass counts are routinely used by managers to decide on the need for suppression tactics. Currently used methods are fixed-area plots (Wilson and Fontaine 1978) and sequential sampling (Kolodny-Hirsch 1986; Fleischer, Ravlin and Reardon 1991) that provide only number of egg masses per acre and have not been a dependable predictor of defoliation (Liebhold et al. 1994). Factors such as forest site, foliar biomass, insect population trends, egg mass size, and phenology are important components of predicting defoliation for purposes of initiating management action.

The sampling support component of GypsES provides the means to design the layout of sampling grids for pheromone, egg mass, or larval sampling. The user can track the placement of pheromone traps or sampling plots, record sampling data, and use the results to generate density estimate layers within GIS. Data derived from initial surveys can be used to extend or articulate further sampling programs. The results of sampling programs provide data used along with other information to set up and prioritize management strategies, including eradication, suppression, or silvicultural alternatives.

Currently, the implementation of truly integrated gypsy moth management programs is constrained by an inability to forecast outbreaks with adequate accuracy. There is substantial evidence that many areas designated for treatment never reach damaging densities. Conversely, populations in stands rejected for treatment often increase to defoliating levels.

#### Treatment -- Suppression and Eradication

The survey portion of GypsES includes two modes of operation: suppression and eradication. *Suppression* mode is used when gypsy moth populations are high enough that defoliation or nuisance is expected to have significant effects on management objectives for the area. *Eradication* mode is used in spot infestations outside the generally infested area and its transition zones. The objective in these spot infestations is to eradicate the gypsy moth. Both modes include expert knowledge on insecticide treatments, mass trapping, delimitation trapping, and pheromone-based mating disruption (Schaub et al. 1990). FSCBG also contains expert knowledge related to insecticide applications, and spray deposition and drift. Treatment effectiveness can be evaluated by comparing pre- and post-treatment values for egg masses, defoliation, pheromone trap catches, and other measures.

Differential GPS files are used to assist pilots in spraying designated areas. DGPS files, created while spraying, show actual flight paths over the treatment area. DGPS files are imported to GypsES and overlaid onto digitized treatment blocks, and can also be entered into the Spray Advisor to locate the actual flight lines for FSCBG prediction of drift and deposition.

#### SUMMARY

While the final touches are being placed on the Version 1.0 release, we are actively pursuing additional enhancement to Version 2.0 of GypsES. These enhancements include: (1) incorporation of the Gypsy Moth Life System Model; (2) further development of the FSCBG interface and its capabilities; (3) addition of economic analyses to the stand damage model; (4) incorporation of silvicultural guidelines rulebases; (5) development of a revised GMMPHEN model; and (6) evaluation of other data input to phenology.

As the reader can see, the GypsES development team has set its goals high -- to provide a field application-oriented, user-friendly toolbox to support decisions and to continually improve on that toolbox as new information and techniques become available. Further information about GypsES, computer system requirements, and availability may be obtained by contacting any of the

authors of this paper. A companion paper and presentation (Ghent et al. 1996) reviews the actual operation of GypsES.

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# **Appendix E: A demonstration of GypsES: The gypsy moth decision support system**



**A DEMONSTRATION OF GYPSES  
THE GYPSY MOTH DECISION SUPPORT SYSTEM**

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Written for Presentation at the  
1996 ASAE Annual International Meeting  
Sponsored by ASAE

Phoenix Civic Plaza  
Phoenix, Arizona  
July 14-18, 1996

**Summary:**

This paper demonstrates GypSES and its use as a decision support system for gypsy moth management. Its menu structure (File, Edit, Windows, Forest, Survey, Treatment, and Help) is highlighted, and an example problem is presented.

**Keywords:**

Decision Support, Aerial Spraying, Gypsy Moth, Computer Software

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# A DEMONSTRATION OF GYPSES THE GYPSY MOTH DECISION SUPPORT SYSTEM

by

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## ABSTRACT

For the last five years a focused effort has been undertaken by the USDA Forest Service in the development and refinement of a decision support system for gypsy moth management. This system, called GypsES, contains mapping capabilities, database management, a forest stand damage prediction model, and the USDA Forest Service aerial spray prediction model FSCBG for the prediction of deposit and drift effects from gypsy moth spray projects. GypsES has been used in operational sites in the Northeast during the last twelve months, and it now seems reasonable to demonstrate the model to a segment of the engineering community that has potentially not yet seen it. This paper provides that demonstration opportunity.

## OVERVIEW

GypsES is a decision support system for gypsy moth (*Lymantria dispar* L.) management being jointly developed by the USDA Forest Service, Northeastern Forest Experiment Station and State & Private Forestry represented by the Northeastern Area, Region 8, and Washington Office Forest Health Technology Enterprise Team -- Davis. GypsES provides decision support to gypsy moth managers by: (1) identifying areas of concern; (2) recommending areas to monitor; (3) recommending areas to treat using direct suppression for established populations, or eradication of localized spot infestations; (4) providing treatment support options for modeling losses with and without treatment; (5) uploading and downloading spray block and spray line information through global positioning system files; and (6) spray deposition and drift modeling. The system is based on GRASS, a public domain set of geographic information system routines. It has been extended to handle all geographic data, a spatially referenced database, and a full-featured map creation and edit facility using topographic backgrounds (1:24000 USGS quadrangles). The system was designed and created with a user-friendly interface written in C under Unix™ X-Windows™ Motif™. Rule-based logic and independent models are integrated to support the decision-making process. The system can produce reports, create maps, and export graphics files for use in other programs. The basic objectives of GypsES are to model the sequence of evaluations necessary for gypsy moth management decisions and to provide managers with a gypsy moth problem with useful tools to make their work more efficient, enable better decisions, and improve effectiveness of treatment.

## SPECIFICATIONS

GypsES is a computer software package developed for forest pest managers who conduct gypsy moth (*Lymantria dispar* L.) management projects. Developed as a decision support system, GypsES provides pest managers with a toolbox of computer-based assistance. Options includes:

- o A geographic information system (GIS) framework enabling the creation of map sets, map analysis, and on-screen digitizing with topographic map backdrops;
- o Geographic positioning system (GPS) files which can be imported and exported;
- o The use of models to predict defoliation, hazard, risk, tree mortality, phenology, biological dose response, and spray deposit and drift;
- o A pheromone trap survey assistance package for eradication projects; and
- o An egg mass sample system design and data management module.

GypsES has several components or modules designed to assist in particular phases of gypsy moth management:

- o A *FOREST* component uses forest data to calculate forest susceptibility. Susceptibility is overlaid with gypsy moth population data to create hazard. Hazard is overlaid with management values to create risk.
- o A *TREATMENT* component can be configured for suppression in established population areas or eradication of localized spot infestations.
- o An *ERADICATION* component assists in establishing pheromone trap grids at varying levels of intensity.
- o A *SPRAY ADVISOR* component assists in spray area delineation, predicting potential forest damage within proposed spray areas, predicting spray deposit and drift, and incorporating actual flight lines obtained from geo-positional navigational systems.

GypsES runs on computers with a 486 DX2-66 and faster (including Pentium™) processor, with at least 32 MB of RAM running UnixWare™ V2.0. Due to the enormous amounts of data used in mapping applications, GypsES requires hard disk storage capabilities in the gigabyte range. It can be modified to run on other types of Unix workstations, but would require a moderate amount of programming depending upon the operating system. All GypsES spatial data formats are based on the GRASS system, a public domain full-featured geographic information system (GIS). GRASS was chosen since: (1) it is powerful; (2) we could obtain the source code; and (3) we do not have to pay license fees to distribute it (U. S. Army Corps of Engineers 1991; Shapiro et al. 1992). A spatially referenced database was developed that uses standard Xbase™ (.DBF) database file formats. A graphical user interface (GUI) written in C using X-Windows™ Motif™ provides the structure for the GypsES menu system. All models, rule bases, and GIS functions are accessed through the GUI menu structure and nested windows. Four work windows are used for all operations. The system will print directly or can save output to graphics files that can then be imported into other programs such as word processors, office publishers, and presentation packages. The report generator can create printed output for many of these operations. GypsES is a large, complex program, containing over 250,000 lines of program source code, not counting some of the models it includes.

## MENU STRUCTURE

The GypsES main menu contains seven major pull-down menu groups. These groups are: file, edit, windows, forest, survey, treatment, and help (as shown in Figure 1 with FSCBG results). Short descriptions of each submenu and some examples of functions available within GypsES follow.

### File Menu

The File menu provides basic file control functions such as deleting, renaming, copying, setting data links, and importing and exporting files. The user can also select the mapset location to work with. This feature allows a user to access multiple locations, each of a size that is on the order of a county or ranger district. This menu also permits the editing of maps and access to many GIS functions such as overlay, combine, reclass, and surface generation.

### Edit Menu

The Edit menu provides the ability to enter or change data, edit data tables, and create or edit map files, including on-screen digitizing. This section is also where many user defaults can be set, such as management objectives for areas, survey parameters, and units of measure.

### Windows Menu

The Windows menu allows the user to change how information is displayed on the screen, including choice of map layers, fonts, colors, symbol size and type, and number of simultaneous windows (one or four). Also, this menu provides for view change (zoom in-out) and masking.

### Forest Menu

The Forest menu allows the user to create hazard layers using GIS layers such as stand boundaries, defoliation, and management objectives. The stand damage model is accessed from this menu for both interactive and pre-defined scenarios. This menu can be used to identify areas where silviculture and other non-insect-focused activities may be beneficial to National Forests and other forest management organizations, even before arrival of gypsy moth in an area. Conducting hazard ratings and simulations of mortality following outbreaks via pre-defined scenarios can identify stands that are of highest priority for silvicultural management. Throughout this menu, one can provide similar prioritization and help in the planning process for eradication and suppression projects.

### Survey Menu

The Survey menu has two different modes: suppression and eradication. In suppression mode it allows editing or viewing of egg mass surveys and their results, generates an egg mass surface using a surface generation routine, and runs the defoliation prediction model to generate a defoliation surface. In eradication mode the Survey menu can help the user create a pheromone trap survey design or detection grid, allow entry of trap data, or view pheromone trap data.

### Treatment Menu

The Treatment menu includes many options. Activities that can be conducted in a pre-treatment situation include: (1) generating a risk layer from hazard and predicted defoliation surface; (2) creating, editing, and viewing a spray block layer; (3) running the phenology model to create a phenology layer to time treatment at peak second-instar development or the time for putting out and picking up pheromone traps; (4) uploading the spray block boundaries to the spray planes via differential global positioning system (DGPS) files; and (5) running the FSCBG spray deposit and drift model with various scenarios, to determine what weather conditions are appropriate to treat in. Post-treatment activities include: (1) downloading actual spray lines from the spray planes via DGPS files; (2) displaying actual spray lines over the spray blocks; (3) running FSCBG using actual spray lines and weather conditions to see the deposit and drift contours that should actually have occurred; (4) calculating egg mass difference layers and overlaying spray blocks to see how effective the treatment was in reducing egg mass densities; (5) overlaying defoliation and spray

blocks to see how effective the treatment was in reducing defoliation; (6) overlaying pheromone trap catches and treatment blocks to determine efficacy of the treatment; and (7) calculating pheromone trap difference layers and overlaying treatment blocks to determine efficacy. The user can develop many reports from within the Treatment menu. Information such as total acres in spray blocks, acreage of each kind of treatment, potential cost of the treatments, grouping of spray blocks by phenology, and many more useful pieces of data are obtainable from the system. In the past, doing these kinds of analyses by hand was very time consuming and mistake-prone.

#### Help Menu

The Help menu system contains context-sensitive help for the user. It contains much of the same information as in the reference manual and is always available to the user. In some instance it contains details not documented elsewhere.

### IMPLEMENTATION

At present GypsES has a beta test group of 12 users, including: (1) Prince William and Fauquier Counties, Virginia; (2) the Arkansas State Plant Board; (3) the Virginia Department of Agriculture and Consumer Services; (4) the Ohio Department of Agriculture; (5) the Indiana Department of Natural Resources; (6) the North Carolina Department of Agriculture; (7) the Tennessee Division of Forestry; (8) the USDI National Park Service, National Capital Region; and (9) USDA Forest Service State & Private Forestry offices in Morgantown, WV, Asheville, NC, Pineville, LA, and Harrisonburg, VA. All users are actively involved in gypsy moth suppression or eradication projects. As we gain experience with these users, additional sites will be added each year, as new users seek access to the system.

### SUMMARY

While the final touches are being placed on the Version 1.0 release, we are actively pursuing additional enhancement to Version 2.0 of GypsES. These enhancements include: (1) incorporation of the Gypsy Moth Life System Model; (2) further development of the FSCBG interface capabilities, including (a) deposit within exclusion zones, (b) optimization/readjustment of flight lines to maximize deposit within spray blocks, (c) linkage of actual flight line information for DGPS data, (d) a consistent help system, and (e) calculating percent success within spray blocks using dose-response interactions; (3) addition of economic analyses to the stand damage model; (4) incorporation of silvicultural guidelines rulebases; (5) development of a revised GMPEHEN model; and (6) evaluation of BioSIM (Regniere and Bolstad 1994; Regniere et al. 1995; and Regniere and Logan 1996) for replacing the current landscape-level temperature input for phenology.

As the reader can see, the GypsES development team has set its goals high -- to provide a field application-oriented, user-friendly toolbox to support decisions and to continually improve on that toolbox as new information and techniques become available. Further information about GypsES, computer system requirements, and availability may be obtained by contacting any of the authors of this paper. An overview of the details behind the development of the GypsES system, and its component parts, may be found in a companion paper and presentation by Twardus et al. (1996). One of the typical results from GypsES -- the spray deposition pattern overlaid over site topography -- is shown in Figure 2.

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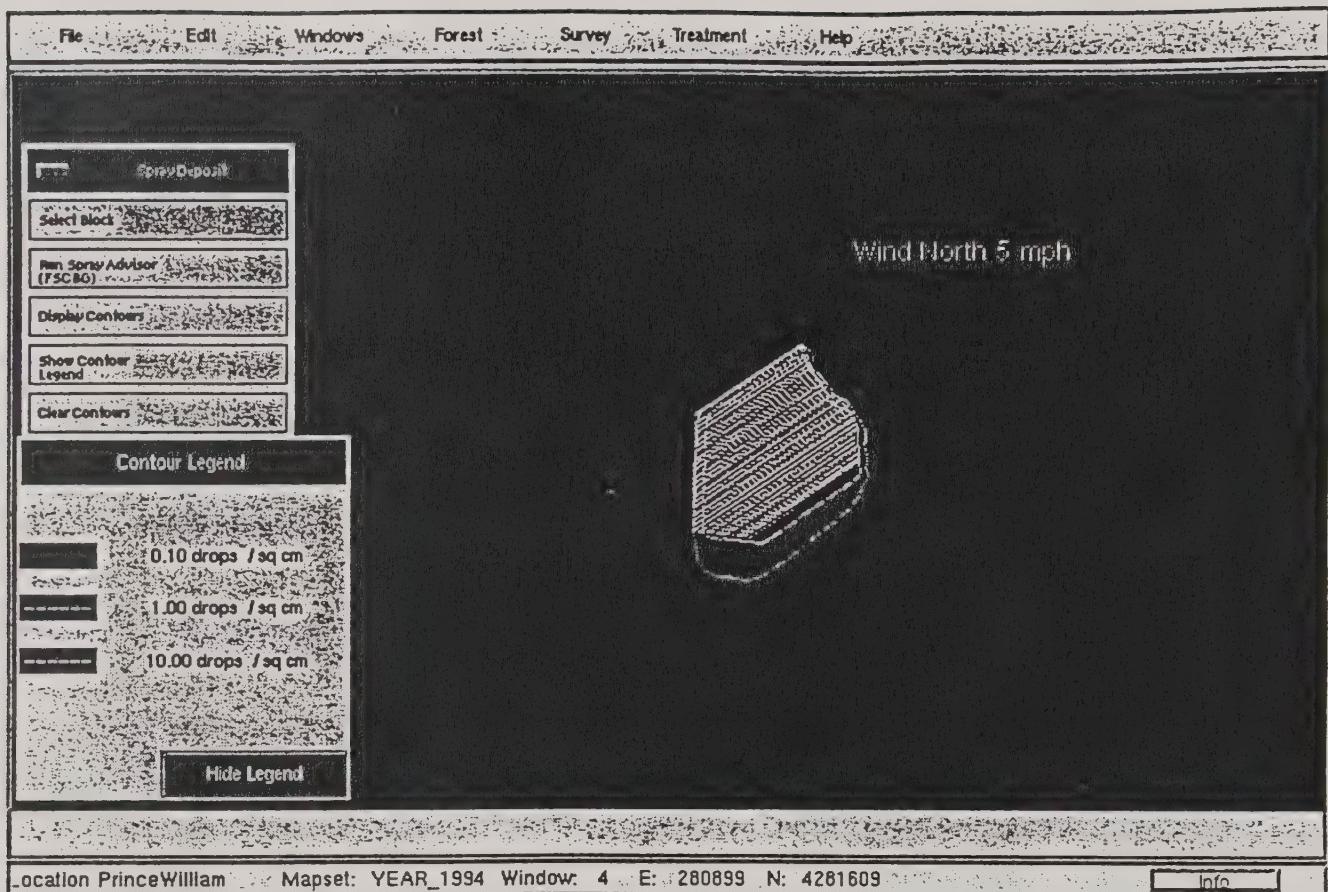


Figure 1. A display of the GypsES menu line (File, Edit, etc.) with Treatment invoked.

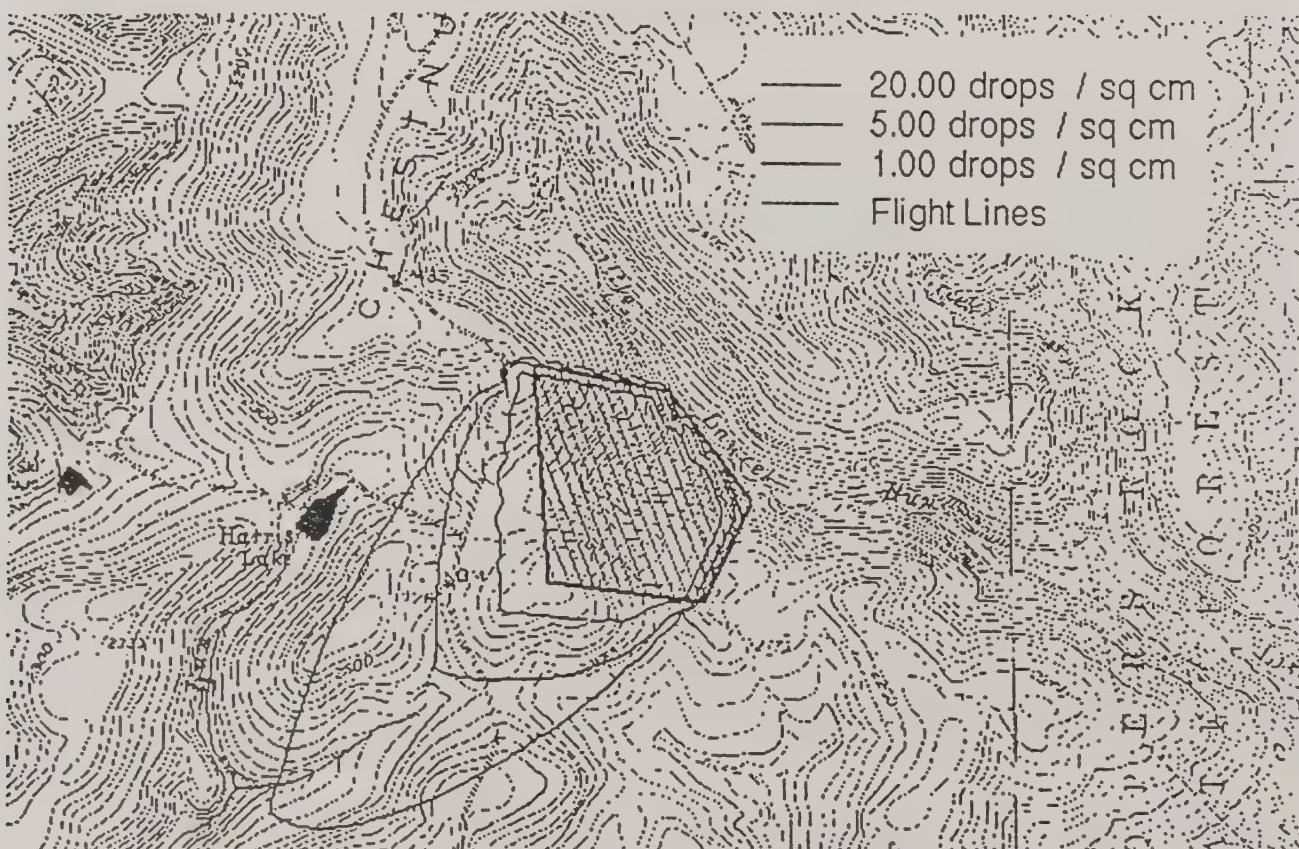


Figure 2. FSCBG predictions overlaid with topographical information.

# **Appendix F: An FSCBG sensitivity study for decision support systems**



## AN FSCBG SENSITIVITY STUDY FOR DECISION SUPPORT SYSTEMS

by

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Written for Presentation at the  
1996 ASAE Annual International Meeting  
Sponsored by ASAE

Phoenix Civic Plaza  
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July 14-18, 1996

### Summary:

This paper reviews the development status of the aerial spray model FSCBG, benchmarked against a systems analysis performed in 1982 on the first operational version of the model. One of the key components of the model is its strong sensitivity to all critical model inputs. These are examined in far greater detail than previously done, as a prelude to inclusion of the parametric effects in Training and Sensitivity modules within FSCBG, acting as a predictive platform for emerging decision support systems.

### Keywords:

Aerial Spraying, Dose-Response, Decision Support, Sensitivity

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# An FSCBG Sensitivity Study for Decision Support Systems

by

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John W. Barry  
Brian Richardson

## ABSTRACT

One of the areas in which predictive models can have great impact is in revealing trends due to changes in model inputs. This is especially true in the case of complex problems, such as the aerial application of pesticides, where the wake formed by the aircraft creates a flow field superimposed over the ambient meteorological background, and into which the spray material (and the resulting drop size distributions), ambient wind speeds, release heights, evaporation, and other parameters affecting this problem, have the possibility of significantly altering the downwind deposition pattern created by the spraying scenario. In this paper we summarize a recent re-examination of the sensitivity of several inputs to the USDA Forest Service aerial spray prediction model FSCBG, and the potential role of this sensitivity in decision support systems, in particular GypsES and SpraySafe Manager. This study extends a previous sensitivity analysis by examining twelve aircraft and a far larger set of application scenarios in a total of over 3000 computer simulations, with the expectation of correlating all of this information into a Sensitivity module in FSCBG, and into Training modules in GypsES and SpraySafe Manager. With the inclusion of dose-response effects and cost-benefit analyses, the development goals of the FSCBG model will then be within reach.

## INTRODUCTION

Over the last 30 years the USDA Forest Service (FS) has been pursuing the development of computer models to predict the dispersion and deposition of aerially released material. The two current models available are AGDISP (Bilanin et al. 1989) and FSCBG (Teske et al. 1993). FSCBG (for Forest Service Cramer-Barry-Grim) predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP (for AGricultural DISPersal) near-wake model, contained within FSCBG, solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on the aircraft. The FSCBG far-wake model begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian dispersion equation to recover ground deposition.

The combination of AGDISP within FSCBG creates a powerful predictive tool for aerial dispersal of spray material. It is now recognized as the industry standard spray dispersion and deposition model, and is currently used by government agencies and private industry in the United States, Canada and New Zealand. The near-wake portion of the model has been selected by the U. S. Spray Drift Task Force (SDTF), and renamed by them as AgDRIFT, as the U. S. model of choice for pesticide registration into the next century (Teske et al. 1996). The Canadian Spray Drift Task Force has decided on the near-wake model as well, accessing it through the user-friendly FSCBG interface, as its model of choice for buffer distance predictions (R. E. Mickle, 1995, private communication). Plans are underway to include FSCBG in three decision support systems (DSS): GypsES, the gypsy moth decision support system under development by the FS, Morgantown, WV, in its Spray Advisor module (Twardus et al. 1996 and Ghent et al. 1996); SpraySafe Manager, an aerial application herbicide decision support system under development by

the FS, Davis, CA, and the New Zealand Forest Research Institute (Teske 1996a and Richardson et al. 1996); and ASPEX, a mosquito control decision support system under development by the USDA and the U. S. Air Force Reserve (Haile, Biery and Mount 1996). In addition, FSCBG has been ported into a multi-component jet fuel evaporation model for the U. S. Air Force (Teske 1996b), and a chemical/biological evaluation tool of near-surface helicopter vulnerability for the U. S. Army (Quackenbush et al. 1996).

The impetus for FSCBG model development can be traced back to a systems analysis of FSCBG, performed by Weeks, Blacksten and Coffey (1982) under a FS contract directed by John W. Barry. A summary of their report, and the modeling consequences thereof, form a large portion of this paper, along with an indication of unfinished business. The two significant remaining tasks in FSCBG model development -- an extensive sensitivity study and dose-response cost-benefit analyses -- will be also discussed: sensitivity in this paper; dose-response in a previous paper (Teske, Barry and Thistle 1996); and cost-benefit in a companion paper prepared for presentation at this conference (Teske, MacNichol and Barry 1996).

## FSCBG SYSTEMS ANALYSIS

In 1981 the FS contracted with Keton, Inc. (Weeks, Blacksten and Coffey 1982) to review the potential for development and implementation of a consistent and inclusive aerial spray model, using as a basis the first released version of FSCBG (Dumbauld, Bjorklund and Saterlie 1980). This version was an extension of previous U. S. Army computer models (Cramer et al. 1972), with the addition of a canopy interception model (Grim and Barry 1975) and some field validation (Waldron 1975). It solved for the dispersal of spray material using a Gaussian slanted-plume line source approximation. The wake of the aircraft was approximated by a constant downwash field generated by the wingtip vortices. The model was as straightforward as possible (program size was critical and computer speed was slow) but functional only for its developers. FSCBG was operational in batch mode on a large mainframe computer accessed by modem. Graphics were nonexistent, and computer problems were frequent. It was, nonetheless, a first important step toward the future.

The Keton report is most impressive for the futuring included in its recommendations. Those familiar with the model at that time were unaware of its potential in the areas suggested, and as a predictive platform for decision support. As a result, implementation of the ideas offered in the report faced immediate technical and financial obstacles, but proceeded forward nonetheless. Subsequent contracting direction by John W. Barry and Robert B. Ekblad of the FS enabled extensive development of FSCBG and AGDISP to their present operational levels. This effort began as far back as 1971, and included field studies for validation purposes and extensive programming by the H. E. Cramer Company, Inc. (HEC) and Continuum Dynamics, Inc.

In their report Weeks, Blacksten and Coffey (1982) identified a number of areas for expansion of the model, in anticipation of its becoming the basis for decision support of aerial application of pesticides. Their suggestions, and the subsequent and on-going response by the FS, are detailed below (alternately summarized in Teske 1994 to that point in time). Each of the reported points include a "completion" scoring system from 0 to 10, interpreted by five recent reviewers of FSCBG model development (J. W. Barry, R. E. Mickle, B. Richardson, M. E. Teske and H. W. Thistle). A designation of 0 indicates that the point has not been addressed (or is now irrelevant); a 10 indicates that the point has been accomplished, and any score in between indicates progress but not completion (a number between 1 and 5 should probably continue to receive attention; a number above 5 has probably been addressed to the extent it will be, given current funding levels). The average scoring is as follows:

*Deposition calculations for all heights simultaneously* (10): FSCBG can recover detailed height profile results through a canopy and solve for three deposition planes at a time.

*Simplified input of droplet spectra* (8): FSCBG contains a drop size distribution library to effect quick recovery of existing droplet spectra, but new data cannot be imported into the model except by time-consuming user entry. Also, there is no analytical method for generating drop size distributions for untested conditions, although such an approach was suggested by Teske and Bilanin (1994) and is being developed by the SDTF (Hermansky, Johnson and Krause 1996).

*Simplified input of stand description data* (7): FSCBG version 5 (to be released Fall 1996) will contain an extensive canopy database for eastern forests involving LiCor measurements; however, validation of the canopy interception model for LiCor has not occurred.

*Summary display programs* (7): FSCBG contains as extensive a graphics capability as any non-Windows program can; the inclusion of FSCBG into DSS (especially those written for the Windows environment) will further enhance the usefulness of the model.

*Interactive program control* (9): FSCBG contains a user-friendly interface, although a rewrite into Windows would standardize its operation considerably.

*Effective wind speed correction* (0): The model used to describe deposition through a canopy in FSCBG cannot permit time-dependent wind data; the best way to determine wind speed and direction changes is with a sensitivity study around the meteorological conditions expected.

*Improvements in the impaction model* (8): The original FSCBG canopy impaction model has been replaced, and extensive validation with field data suggests that the model now meets expectations. However, it is not as detailed as some investigators would like.

*Test evaporation routine using existing data* (10): The evaporation models used in FSCBG have been validated by the SDTF (Teske and Hill 1995).

*Alter the program to allow model runs with any flight pattern* (4): FSCBG does not currently have the capability of solving for different release heights on different flight lines, or importing known GPS flight line data. The spraying scenario (confined to a single release height) will however be able to be entered more generally in version 5.

*Alter the simulation to allow forest edge effects beyond the canopy* (2): Currently, FSCBG can solve only for canopy on or off, but version 5 will permit canopy changes within the near-wake model. The technical intent of this improvement will be difficult to achieve.

*Deposition accounting by tree type* (10): Three tree types may be considered simultaneously in any FSCBG simulation.

*Slope correction for canopy penetration* (0): Only horizontal terrain can be assumed in FSCBG; the report suggestion of a correction factor easily added to the model is too simplistic.

*Improved fitting of impaction coefficient and probability of penetration* (10): Confirmed by extensive canopy validation studies since 1973.

*Near-site drift measure of hazard* (6): FSCBG predicts ground deposition and downwind drift from an assumed spray scenario; the interpretation of these results is left for outside the program (in DSS); the addition of a dose-response function and database in version 5 will benefit the model in this area.

*Herbicide measure of effectiveness* (4): Additional tools need to be added to FSCBG to interpret in-swath deposition and dose-response effects as well; some of them will be added in version 5.

*Simple insecticide measure of effectiveness* (4): Same comments as above.

*Sensitivity analysis* (10): Two extensive sensitivity studies have been undertaken, the second of which (Teske 1996c) is summarized later in this paper.

*Aerial spray mission cost computation* (8): Separate computer models accomplish this task, although their inclusion into FSCBG and DSS will be necessary for effective cost-benefit analyses.

*Interim documentation* (10): Documentation of the model has always been considered a priority throughout its development.

*Research data on modes of toxicity* (0): Although such studies have been undertaken in the past, and are ongoing, they do not form a part of the FSCBG model structure.

*Droplet spectra data* (7): FSCBG contains a library of available data, but the extensive data collected by the SDTF is currently proprietary, as is the SDTF drop size distribution model.

*Additional foliage distribution descriptions* (9): The previously described eastern forest database and the ability of the canopy model to predict penetration and impaction with LiCor data, will be important features of FSCBG.

*Improved wake model* (10): The inclusion of the AGDISP near-wake model covers all the deficiencies of the original aircraft wake assumptions in FSCBG.

*Simplified wind direction deviation inputs* (9): The Gaussian model now includes stability effects, and we are currently working toward the addition of such effects in the near-wake model as well (Thistle, Teske and Barry 1996).

*Simplified wind profile generation* (6): Meteorological instrumentation has received high priority from the USDA Forest Service, but hope for a technique to interpret field conditions based on a minimum amount of data is too far-reaching to be practical at this time.

*Persistence and photodegradation module* (0): Although models are being developed elsewhere to estimate pesticide effectiveness after deposition, such models are not yet included in FSCBG.

*Dosage prediction within the canopy* (0): The need has not presented itself for this model extension, and its implementation would be difficult.

*Routine to adjust model predictions based on field managements* (0): Real-time correction of model predictions may eventually occur with interactive GPS data, but the technology is not currently available. This goal is partially achieved by the sensitivity studies (giving an indication of how changes in field conditions will influence results) and by simply rerunning the model on a fast portable computer carried to the field project.

*Empirical impaction model* (7): The impaction model has been improved, but not to the detail suggested here (to include micrometeorological, electrostatic and surface roughness and adhesion effects, and insect body geometry).

*Mesoscale model interface* (3): A step in this direction is VALDRIFT (Thistle 1996), but an intimate connection with FSCBG is not planned.

*Improved insecticide effectiveness module* (0): The connection between FSCBG deposition predictions and pesticide effectiveness is just now being explored in DSS.

*Model validation* (10): FSCBG model validation has been ongoing and is continuing as an essential part of model development.

*User documentation* (10): FSCBG documentation has received the same level of effort.

*Maintenance documentation* (0): As the model moved to the personal computer, and into simple subroutine form, with support from a User Group, the need for a maintenance document became less important than when the program was resident on a mainframe.

*Empirical evaporation descriptions for major formulations* (8): For most spray materials, treating them like water when they evaporate appears successful (Teske and Hill 1995), although a wind tunnel study is the only way to be sure.

*Spray adjuvant effects* (8): Spray adjuvants are the focus of current research, and their effects are contained in the existing FSCBG libraries and SDTF databases. Trying to keep up with new spray materials and additives (for drop size distributions and evaporation effects) would be a thankless job, with no end in sight.

*Synopsis versions for portable calculators* (10): Personal computers solve this problem.

*Synopsis documentation* (0): Not relevant.

*Parameterization of the Monte Carlo simulation* (0): Not relevant; as the canopy model no longer uses a random number solution technique, but instead makes use of penetration probability.

*Adaptation of a crop canopy deposition model* (8): The existing canopy model (especially with appropriate LiCor measurements) generates a prediction of crop deposition; however, little data are available regarding canopy effects on the released spray cloud.

*Synopsis version of open area module* (0): Not relevant.

*Further validation* (10): Validation continues, unless slowed or stopped by funding levels.

*Update user and maintenance documents* (10): Clearly, a commitment exists toward the User Group and maintaining model support, but funding will always be a problem as well.

By this estimate the overall development and progress of the FSCBG model is rated 6.5, a clear indication of the support given it by the FS. The model now runs on personal computers, with extensive graphical capability, the addition of features not conceived by the Ketron report, a User Group of 180 members, over 120 reports and publications (in the last 10 years) to support model development and validation, and implementation of the model into other applications and uses. However, there are a number of areas that have not been fully implemented, and other tasks that are relevant now that personal computers are so easily available. These tasks become part of the unfinished business of the FSCBG model.

## UNFINISHED BUSINESS

A strong conclusion of the Ketron report was the need for the development of a biological effectiveness module. Such a module would include measures of effectiveness defined by: (1) target pest mortality; (2) changes in program costs; (3) increased product growth; (4) increased

economic value; and (5) increased productive capacity of fixed resources. These words of course all point to dose-response and cost-benefit, and form the basis for this session of the conference as discussed by Hall (1996). They also form a part of the work on FSCBG that has not yet been accomplished. These tasks include the following:

*Completion of tasks:* Current FSCBG funding includes the addition of GPS flight line data entry, simple forest edge effects, and a dose-response database, in addition to additional graphical capability. These features will be a part of FSCBG version 5 and the DSS under development. The real-time version of FSCBG (Teske 1995) must still be validated. The extended sensitivity study is summarized below.

*Drop size distribution model:* To fill a void in FSCBG prediction capability, the algorithm for generating drop size distribution profiles from fundamental nozzle and spray material properties, as developed by the SDTF, should be included in FSCBG.

*Cost-benefit:* Cost-benefit is now emerging as a need within any model or DSS proposing to encompass the application of pesticides. Dose-response databases play a large part in the ability of a model to forecast cost-benefit (dose-response studies include Ray et al. 1996, MacNichol and Teske 1996, and Teske 1996d). Our views on the implementation of cost-benefit into FSCBG are collected in Teske, MacNichol and Barry (1996).

*Windows interface:* The user interface to FSCBG must be rewritten if the model is to continue in a "stand-alone" capacity two years from now.

*Maintenance and support:* With the anticipated retirement of the original manager of FSCBG (John W. Barry), the future of managing the User Group, handling programming errors, and offering improvements to the model, is uncertain.

While FSCBG is a nearly mature model, it is perhaps one year away from completion. For all the years that the model was diligently developed by the FS, its last steps will have to be funded by other organizations, or these steps will not be taken.

## COOPERATION IN MODEL DEVELOPMENT

The development of FSCBG has been sponsored since 1973 by the FS and the U. S. Army, under the leadership of John W. Barry. HEC initially developed the code, drawing upon Gaussian techniques developed by Cramer, Calder and other in the 1950s and 1960s (Cramer et al. 1972). The first forestry application of the Cramer model was in 1971 when the U. S. Army contracted the HEC to make a series of dosage profiles using the Cramer model for a FS and U. S. Army cooperative study conducted on the Nez Perce National Forest, Idaho. For that study the model pre-study predictions of insect mortality matched the post spray insect mortality (Waldron 1975). The Idaho study, and others in Montana from 1972 to 1975, provided data for initial FSCBG model development and were all supported with U. S. Army funding. The FS became a source of financial support in 1977 when HEC was contracted for major enhancements to FSCBG. HEC continued as the FSCBG model contractor until late in 1988 when Continuum Dynamics, Inc. was awarded a contract to complete the insertion of AGDISP into FSCBG. Since then, the FS has been the primary financial supporter of FSCBG. Several other organizations have supported FSCBG development, enhancements and/or technology transfer, including the U. S. Air Force, the New Zealand Forest Research Institute, and Environment Canada. It is unfortunate that the agricultural extension and research communities, and agricultural chemical companies, have not responded by sharing in development costs and extending the model to agricultural applications as well. The current redirection of FS programs, the new ecosystem approaches to resource management, and the anticipated reduction in funding levels, join to dictate significant reduction

and possible elimination of further USDA funding for FSCBG. Clearly, future development will have to be supported by the User Group or other users. FSCBG currently stands as the world's primary aerial spray dispersion model, and the User Group has the responsibility to sustain this status.

## AN EXTENDED SENSITIVITY STUDY

One of the important modules envisioned in any DSS should be that of training, in addition to operational use. This module would enable the user to examine "what-if" scenarios by changing inputs to the model and quickly recovering trends, without spending any time waiting for the model to run through its paces for each of the chosen variations. To accomplish this task, a sizable database of previously generated FSCBG runs is therefore needed, to enable interpolation for the answers posed by the user. Such a database would be an extension of our previous sensitivity study (Teske and Barry 1993), and would examine only those inputs shown to be most important to the predicted near field and far field deposition.

The complete report is contained in Teske (1996c). Model predictions were saved as ground deposition patterns of percent applied nonvolatile. Several parameters could then be generated by examining these profiles:

*Swath width:* Obtained using the approach discussed in Teske, Twardus and Ekblad (1990), by overlapping the predicted single flight line deposition pattern to generate multiple flight lines, then optimizing the results for a coefficient of variation (COV) of 0.3.

*In-swath mean deposition and variance:* A second result from the optimization is the determination of the mean in-swath deposition level and the standard deviation of the in-swath deposition about the mean. These two numbers feed directly into dose-response (Teske 1996a).

*Buffer distance:* With the optimized overlapped deposition pattern, the distance downwind from the aircraft centerline to a specified level of percent applied nonvolatile can then be determined.

The generated database contains the following information (sensitivity effects are summarized in Table 1; Figures 1 and 2 show typical results for all aircraft and nozzle types):

*Aircraft type and base case configurations* (24 model runs): The study included the Air Tractor AT-301, Ayres Turbo Thrush, Bell 205A, Bell JetRanger III, Cessna Ag Wagon, Fletcher, Hiller Soloy Turbo, Hughes 300C, Hughes Cayuse 500C, Schweizer Ag Cat, and Squirrel, with Micronair AU5000 and Beecomist 360A rotary atomizers and D8/46 fan nozzles. Predictions of the above parameters show that changes in aircraft type can change results by a factor of 20 over the range considered in the sensitivity study.

*Boom width* (120 additional model runs): Varied between 50 and 100 percent of wingspan or rotor diameter. Changes in boom width can change results by a factor of 2 over the range considered.

*Release height* (120 additional model runs): Varied between 5 and 30 m. Changes in release height can change results by a factor of 9.

*Spraying speed* (114 additional model runs): Varied between 20.6 and 61.7 m/sec for the fixed-wing aircraft, and 10.3 and 51.4 m/sec for the helicopters; also examined the FSCBG library to extract drop size distribution effects as a function of spraying speed. Changes in spraying speed can change results by a factor of 6.

*Aircraft weight* (96 additional model runs): Varied between 0.5 and 1.5 times their nominal values. Changes in aircraft weight can change results by a factor of 4.5.

*Wind direction* (72 additional model runs): Varied between 0 and 90 degrees relative to the flight line direction. Changes in wind direction can change results by a factor of 6.

*Wind speed* (72 additional model runs): Varied between 1.39 and 5.56 m/sec (2 m above the ground). Changes in wind speed can change results by a factor of 6.5.

*Nonvolatile fraction* (120 additional model runs): Varied between 0.085 and 1.0 (no evaporation). Changes in nonvolatile fraction can change results by a factor of 2.

*Wetbulb temperature depression* (144 additional model runs): Varied between 0 (no evaporation) and 12 deg C, encompassing the sensitivity of both ambient temperature and relative humidity. Changes in wetbulb temperature depression can change results by a factor of 2.

*Nozzle type* (78 additional model runs): Examined the variation from eight drop size distributions, as indicative of changes in volume median diameter (VMD): Micronair AU5000 with VMD = 74.5  $\mu\text{m}$ ; Beecomist 360A with VMD = 125.1  $\mu\text{m}$ ; D8/45 with VMD = 220.8  $\mu\text{m}$ ; D8/46 with VMD = 314.0, 423.9 and 613.0  $\mu\text{m}$ ; Delafoam with VMD = 815.5  $\mu\text{m}$ ; and D6 Jet with VMD = 1075.5  $\mu\text{m}$ . Changes in nozzle type can change results by a factor of 18.

*Specific gravity* (150 additional model runs): Varied from 0.8 to 1.2, plus examined side-by-side comparisons with available nonunity spray materials found in the FSCBG library and water. Changes in specific gravity can change results by a factor of 2.

*Release height and wind speed* (688 additional model runs): Varied release height between 5 and 30 m and wind speed between 1.39 and 5.56 m/sec to generate joint effects.

*Release height and wetbulb temperature depression* (1302 additional model runs): Varied release height between 5 and 30 m and wetbulb temperature depression between 0 and 12 deg C to generate joint effects.

With the database developed, we can then move into a numerical algorithm that recovers data trends from any well-defined aerial application scenario. What is anticipated here is an influence coefficient approach, developing rates of change for all tested variables as a function of the changed input, generalized for any fixed-wing aircraft and helicopter from the ones tested. The Training module in SpraySafe Manager (and other DSS), and the Sensitivity option in FSCBG, will then access these data to make quick estimates of the effect of input parameter changes. In this way the model will provide a fast way of responding to input changes, without going through the motion of running the model. Operational planning would be accomplished much faster as well.

## CONCLUSIONS

This paper reviews an early systems analysis and subsequent development of FSCBG, including the visioning of the additional features needed to make the model a well-used prediction tool for the aerial application of pesticides. The overall accomplishments to date, supported almost entirely by the USDA Forest Service, are significant, although several areas of research and implementation will need to be further supported by the User Group.

An extended sensitivity study -- essential to any DSS estimation, operational, or training module -- is also summarized. Results of a previous study are confirmed, and emphasize the importance of: (1) aircraft type; (2) volume median diameter, (3) release height, (4) wind speed, (5) wind direction, (6) spraying speed, (7) aircraft weight, (8) boom width, (9) nonvolatile fraction, (10) specific gravity, and (11) temperature and relative humidity, on the aerial application of pesticides.

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TABLE 1: SENSITIVITY STUDY EFFECTS LEVEL.

A change in the variable in the first column can change results by the factor given in the second column.

Variable	Possible Effects Factor
Aircraft Type	20.0
Nozzle Type (VMD)	18.0
Release Height	9.0
Wind Speed	6.5
Wind Direction	6.0
Spraying Speed	6.0
Aircraft Weight	4.5
Boom Width	2.0
Nonvolatile Fraction	2.0
Specific Gravity	2.0
Temperature and Relative Humidity	2.0

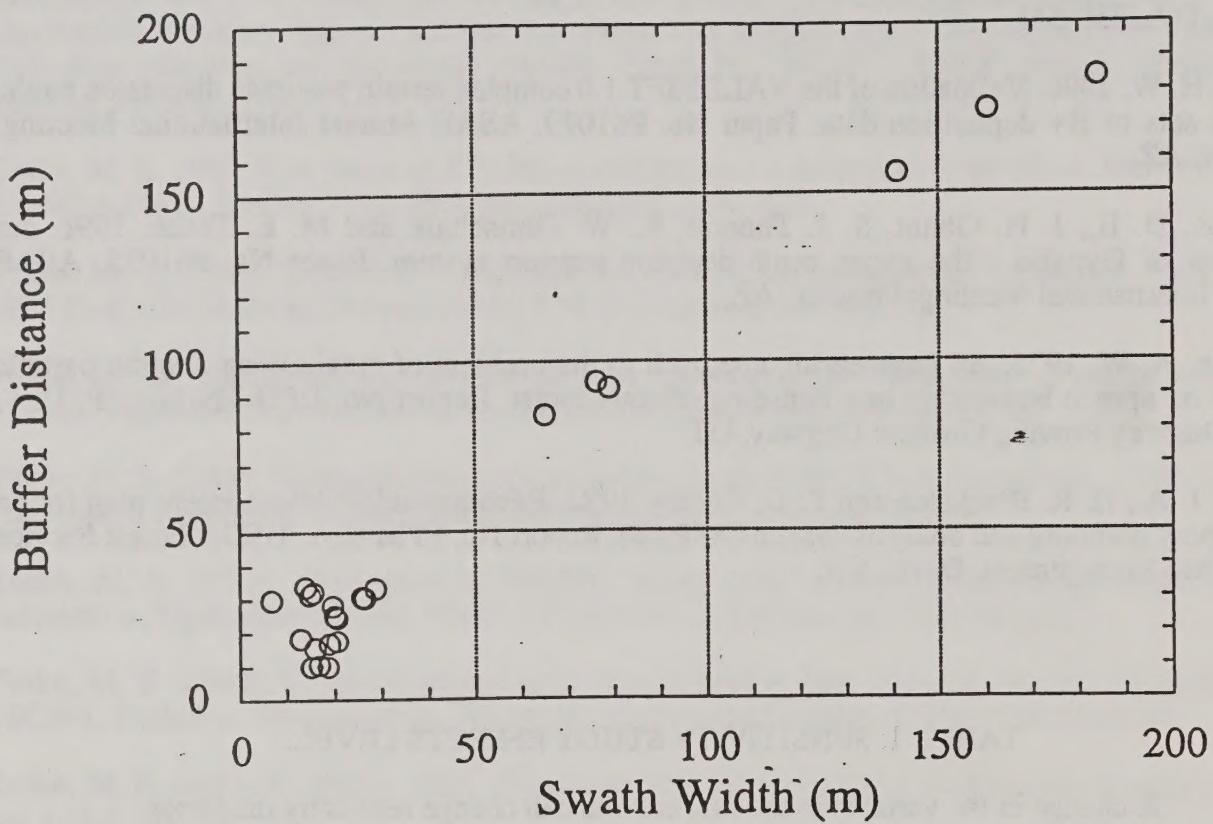


FIGURE 1: Display of the variability of swath width and buffer distance in the 24 base case configurations (each circle represents one FSCBG calculation).

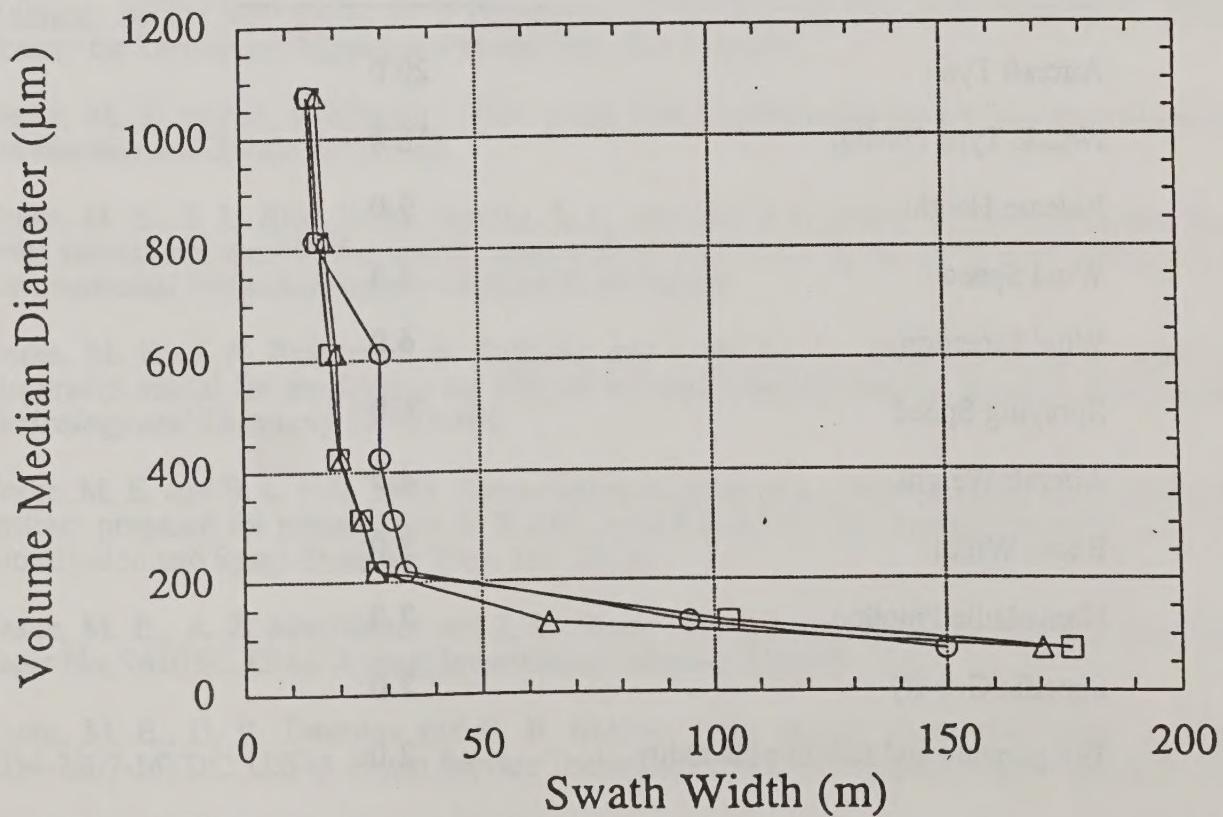


FIGURE 2: Sensitivity of swath width to volume median diameter. The configurations are: Bell 205A (circles); Bell JetRanger III (squares); and Hiller Soloy Turbo (triangles).

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